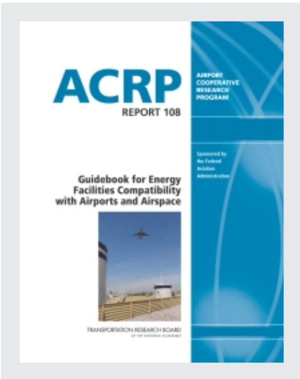

Guidebook for Energy Facilities Compatibility with Airports and Airspace

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AUTHORS

Stephen B. Barrett, Philip M. DeVita, and Jesse R. Lambert; Airport Cooperative Research Program; Transportation Research Board; National Academies of Sciences, Engineering, and Medicine

AIRPORT COOPERATIVE RESEARCH PROGRAM

ACRP REPORT 108

Guidebook for Energy Facilities Compatibility with Airports and Airspace

Stephen B. Barrett
Philip M. DeVita
Jesse R. Lambert
HARRIS MILLER MILLER & HANSON INC.
Burlington, MA

IN ASSOCIATION WITH

Clifford K. Ho
SANDIA NATIONAL LABORATORIES
Albuquerque, NM

Bryan Miller
BEM INTERNATIONAL, LLC
Sheridan, WY

Yu Zhang
UNIVERSITY OF SOUTH FLORIDA
Tampa, FL

Mary Vigilante
SYNERGY CONSULTANTS, Inc.
Seattle, WA

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AIRPORT COOPERATIVE RESEARCH PROGRAM

Airports are vital national resources. They serve a key role in transportation of people and goods and in regional, national, and international commerce. They are where the nation's aviation system connects with other modes of transportation and where federal responsibility for managing and regulating air traffic operations intersects with the role of state and local governments that own and operate most airports. Research is necessary to solve common operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the airport industry. The Airport Cooperative Research Program (ACRP) serves as one of the principal means by which the airport industry can develop innovative near-term solutions to meet demands placed on it.

The need for ACRP was identified in *TRB Special Report 272: Airport Research Needs: Cooperative Solutions* in 2003, based on a study sponsored by the Federal Aviation Administration (FAA). The ACRP carries out applied research on problems that are shared by airport operating agencies and are not being adequately addressed by existing federal research programs. It is modeled after the successful National Cooperative Highway Research Program and Transit Cooperative Research Program. The ACRP undertakes research and other technical activities in a variety of airport subject areas, including design, construction, maintenance, operations, safety, security, policy, planning, human resources, and administration. The ACRP provides a forum where airport operators can cooperatively address common operational problems.

The ACRP was authorized in December 2003 as part of the Vision 100-Century of Aviation Reauthorization Act. The primary participants in the ACRP are (1) an independent governing board, the ACRP Oversight Committee (AOC), appointed by the Secretary of the U.S. Department of Transportation with representation from airport operating agencies, other stakeholders, and relevant industry organizations such as the Airports Council International-North America (ACI-NA), the American Association of Airport Executives (AAAE), the National Association of State Aviation Officials (NASAO), Airlines for America (A4A), and the Airport Consultants Council (ACC) as vital links to the airport community; (2) the TRB as program manager and secretariat for the governing board; and (3) the FAA as program sponsor. In October 2005, the FAA executed a contract with the National Academies formally initiating the program.

The ACRP benefits from the cooperation and participation of airport professionals, air carriers, shippers, state and local government officials, equipment and service suppliers, other airport users, and research organizations. Each of these participants has different interests and responsibilities, and each is an integral part of this cooperative research effort.

Research problem statements for the ACRP are solicited periodically but may be submitted to the TRB by anyone at any time. It is the responsibility of the AOC to formulate the research program by identifying the highest priority projects and defining funding levels and expected products.

Once selected, each ACRP project is assigned to an expert panel, appointed by the TRB. Panels include experienced practitioners and research specialists; heavy emphasis is placed on including airport professionals, the intended users of the research products. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, ACRP project panels serve voluntarily without compensation.

Primary emphasis is placed on disseminating ACRP results to the intended end-users of the research: airport operating agencies, service providers, and suppliers. The ACRP produces a series of research reports for use by airport operators, local agencies, the FAA, and other interested parties, and industry associations may arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by airport-industry practitioners.

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The members of the technical panel selected to monitor this project and to review this report were chosen for their special competencies and with regard for appropriate balance. The report was reviewed by the technical panel and accepted for publication according to procedures established and overseen by the Transportation Research Board and approved by the Governing Board of the National Research Council.

The opinions and conclusions expressed or implied in this report are those of the researchers who performed the research and are not necessarily those of the Transportation Research Board, the National Research Council, or the program sponsors.

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Michael R. Salamone, *ACRP Manager*
Theresia H. Schatz, *Senior Program Officer*
Terri Baker, *Senior Program Assistant*
Eileen P. Delaney, *Director of Publications*
Natassja Linzau, *Editor*

ACRP PROJECT 02-38 PANEL
Field of Environment

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Douglas M. Moss, *AeroPacific Consulting, Reno, NV*
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Christine Gerencher, *TRB Liaison*

Cover photo: Courtesy of Adam Parsons, Environmental Operations Analyst, Dallas/Fort Worth International Airport.

FOREWORD

By Theresia H. Schatz
Staff Officer
Transportation Research Board

ACRP Report 108: Guidebook for Energy Facilities Compatibility with Airports and Airspace describes practices for aviation safety associated with planning, developing, and constructing energy production and transmission technologies at and around airports. The guidebook is a resource for aviation and energy industry professionals to improve energy technology project siting at and around airports in order to meet U.S. domestic energy production needs while ensuring a safe and efficient national airspace system.

The guidebook considers different types of energy technologies that could be installed in and around airports, including, but not limited to, solar, wind, power generation plants, oil and gas drilling, and electricity transmission lines and towers. Best practices and guidelines for a wide range of types and sizes of airports compatible with air transportation systems, for all airspace, including special use airspace, both on and off airports are provided. In addition, design and siting or location guidelines for each of these types of energy technologies are provided to mitigate and minimize the impact on aviation, such as, height and distance criteria for wind turbines, distance and angular criteria for solar panels, and thermal plume effects on aviation.

Projected demand for energy will increase in the upcoming years requiring the development of new or expanded energy sources. Recognizing the need to significantly increase energy production and transmission infrastructure, energy stakeholders must consider aviation safety and airport safety concerns. The FAA recently published *Technical Guidance for Evaluating Selected Solar Technologies on Airports* (November 2010). The *ACRP Synthesis 28: Investigating Safety Impacts of Energy Technologies on Airports and Aviation* takes another step in describing how various energy technologies affect airports. Initial findings and discussions with experts suggest, though, that the scope of the safety impacts may be greater, extending far beyond the immediate airport environs. This research further evaluates the safety effects that energy technologies may have on the air transportation system (including aircraft in flight and on and off the airport environment) and develops best practices to address such effects.

This research was conducted under ACRP Project 02-38 by Harris Miller Miller & Hanson Inc. in association with Sandia National Laboratories, BEM International, University of South Florida, and Synergy Consulting. Their research consisted of collecting and reviewing data received from direct investigations with the experts associated with government, academia, and private industry on energy technologies and its impact on aviation and airports. The research findings are provided as best practices organized by technology including general siting and design criteria.

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The research reported herein was performed under ACRP Project 02-38 by Harris Miller Miller & Hanson Inc. (HMMH).

Stephen B. Barrett, Director of Clean Energy at HMMH, was Principal Investigator. The other authors of this report are Philip M. DeVita, Director of Air Quality, and Jesse R. Lambert, Senior Consultant, HMMH; Clifford K. Ho, Ph.D., Concentrating Solar Technologies Department, Sandia National Laboratories; Bryan Miller, Lt Col USAF (Ret.), Command Pilot, Principal, BEM International, LLC; Yu Zhang, Ph.D., Assistant Professor, Civil and Environmental Engineering Department, University of South Florida; and Mary Vigilante, Principal, Synergy Consultants, Inc.

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CONTENTS

Note: Many of the photographs, figures, and tables in this report have been converted from color to grayscale for printing. The electronic version of the report (posted on the Web at www.trb.org) retains the color versions.

Executive Summary

The energy industry is going through a transformation driven in part by public policy and sustained by technological innovation and market development. These changes have led to a geographic expansion in the deployment of energy projects producing an increase in potential conflicts with airports and airspace. *ACRP Synthesis 28: Investigating Safety Impacts of Energy Technologies on Airports and Aviation*, reviewed the state of information and airport practice for this topic. The researchers concluded that additional research is needed to further evaluate the safety effects that energy technologies may have on the air transportation system and to develop best practices to address such effects. ACRP 02-38, "The Guidebook for Energy Facilities Compatibility with Airports and Airspace," provides a comprehensive review of the National Airspace System (NAS) and the potential effects of energy technologies on the NAS, followed by best practices and guidelines for avoiding, minimizing, and mitigating impacts.

The Guidebook provides a thorough review of airspace and energy technologies as a basis for assessing impacts. The airspace review provides a definition of the NAS and discusses its components from take-off to landing, Federal Aviation Administration (FAA) protection of airspace as a public good, airspace users types, and ways in which airspace may change in the future. The energy technologies reviewed that have a potential impact on airports and airspace are solar, wind, oil and gas drilling, power plant stacks and cooling towers, and electrical transmission. The potential impacts associated with these technologies are solar glare, radar interference, and turbulence from wind (as well as meteorological evaluation towers as a hazard), physical obstructions and ancillary hazards from oil and gas drilling, thermal plume turbulence from power plants, and physical obstructions from electrical transmission. Some of these impacts are physical and, therefore, more readily quantifiable, while others are non-physical and more difficult to define.

A review of the potential impacts of energy facilities impacts on airports and airspace must be conducted in the context of some core concepts about the role of energy and aviation in the country, including the following:

- The expansion and modernization of our domestic energy development is central to our national interests.
- The NAS, also critical to our national interests, is a finite resource that must be maintained and enhanced to ensure safe and efficient air travel.
- Energy and aviation are both critical to the future economic prosperity of the country.
- It is best to avoid energy impacts on aviation; impacts should be minimized and mitigated only when necessary.

Research for this Guidebook also revealed some general conclusions about the difficulty of assessing potential impacts on airports and airspace. These conclusions are not exclusive to energy technologies but, due to the increase in potential conflicts posed by energy technologies, they are an important part of assessing aviation safety impacts from energy and identifying best practices and guidelines.

- It is simple to determine if a structure results in a physical impingement of airspace but it is complex to determine if the physical impingement results in a significant impact.
- Structures that do not result in a physical impingement of airspace may still pose a significant risk to aviation.
- Non-physical impacts (e.g., glare and turbulence) are not well defined, making it difficult to develop associated guidance.
- Federal Aviation Administration (FAA) reviews on-airport energy projects but may not review many off-airport projects.

The Guidebook summarizes a number of new research initiatives, some of which were conducted as part of or in association with this project, and others that were entirely independent. These research efforts were used to inform best practices and guidelines, including the following:

- Glare measurements from commercially available solar panels.
- Glare modeling and model verification.
- Survey of pilots on their experience with glare.
- Wind turbine radar research, conducted under the Interagency Field Test and Evaluation Program (IFT&E).
- Development of new wind power and thermal plume turbulence modeling tools.
- Survey of airports located proximate to new electrical transmission infrastructure.

The main purpose of the Guidebook is to present best practices for aviation safety associated with planning, developing, and constructing energy production and transmission technologies at and around airports. Fulfilling this objective was a challenge given the variety of technologies and types of impacts, as well as the general lack of performance standards available for assessing impacts. To meet this challenge, Chapter 4, "Guidance" provides a set of concise guidelines and practical considerations for siting and managing energy projects in the aviation environment. Chapter 4 can be used as a stand-alone reference tool with information presented in two formats. The first section lists best practices for each energy technology, allowing users to quickly review issues particular to a proposed project. The second section includes general guidance for siting structures to avoid physical obstructions based on the height of the structure, as well as other design observations for each energy technology type.

Upon reflection, the intersection of energy and aviation has received a significant amount of attention over the past few years. The result of this body of work has been the development of several new tools to help energy and aviation professionals improve the siting of energy projects, including those advocated for by airports to increase revenue for their airport business. While several areas requiring additional research remain, successful energy project siting will continue to depend on close coordination between project stakeholders and regulatory officials, combined with the utilization of new knowledge related to aviation impacts from energy technologies and new tools for measuring and minimizing these impacts.

CHAPTER 1

Introduction

1.1 ACRP Problem Statement

Energy demand projections continue to indicate growth well into the future, necessitating continued innovation and expanded capacity of our energy supply and distribution network. Efficiency improvements to electricity and transportation fuel systems will reduce the average amount of energy used per person, but aggregate energy consumption will maintain its rise over the long term due to continuous population growth and increased demand in the industrial and commercial sectors.[1]

Various energy technologies are already competing to meet this projected demand, including fossil fuels and renewable resources. Widespread use of hydraulic fracturing (i.e., "fracking") and directional drilling for natural gas and petroleum, as well as technological advances in wind and solar energy, have dramatically increased energy supplies and reduced costs. Based on these trends, the U.S. Energy Information Agency (EIA) projects natural gas, renewables, and biofuels to all grow in their total share of U.S. energy use, with corresponding reductions in coal and petroleum use (see Figure 1.1).[2] According to the Federal Energy Regulatory Commission (FERC), biomass, geothermal, solar, hydro, and wind power accounted for 49.10 percent of all new electric power generating capacity installed in 2012,[3] accounting for 15.75 percent of total capacity as of April 2013.[4] In fact, renewables represented 84.5 percent of all new generation in-service from January to April 2013, up 5.6 percent over the same period in 2012.[5]

These industry trends indicate that new energy exploration will be pervasive and will involve projects at sites that were previously considered infeasible or unconventional, including on or near airport properties. Airport sponsors may be proponents of energy projects on airport property as a way to offset energy costs or generate additional revenue. Such projects do pose certain complications, though, as airport sponsors may not be prepared for the financial and operational risks of the energy industry. Furthermore, laws and policies regarding the impact of energy facilities on aviation activities are not yet well defined. Project stakeholders must be familiar with existing regulations and technical standards, as well as aware of ongoing developments as government oversight increasingly reflects industry trends.

The FAA is currently creating new technical guidance materials and updating existing documents to assist stakeholders and airport sponsors involved with energy technology projects. In November 2010, the FAA published *Technical Guidance for Evaluating Selected Solar Technologies on Airports*. In June 2011, *ACRP Synthesis 28: Investigating Safety Impacts of Energy Technologies on Airports and Aviation* further explored the safety impacts of a broad variety of energy technologies. *ACRP Synthesis 28* states that, in recent years, "a significant amount of research has been conducted . . . on energy technologies and their safety impacts on airports and aviation," including projects by the FAA, the California Energy Commission, the Department of Energy's Sandia National Laboratories, and the U.S. Transportation Command (TRANSCOM). The FAA has also "actively administer[ed] airspace reviews to assess the potential impact of energy projects . . . in concert with state agencies." While the study noted that several measures have been implemented by regulatory agencies to mitigate the impacts of energy technologies, it recommended

[1] U.S. Energy Information Agency (EIA), "Market Trends—U.S. Energy Demand," May 2, 2013: http://www.eia.gov/forecasts/aeo/MT_energydemand.cfm#renew_natgas.

[2] Ibid.

[3] *Renewable Energy Focus*, "Half of new U.S. power capacity in 2012 renewable—FERC," January 22, 2013: http://www.renewableenergyfocususa.com/view/30367/half-of-new-us-power-capacity-in-2012-renewable-ferc/.

[4] U.S. Federal Energy Regulatory Commission (FERC), Office of Energy Projects, "Energy Infrastructure Update," April 2013: http://www.ferc.gov/legal/staff-reports/2013/apr-energy-infrastructure.pdf.

[5] Ibid.

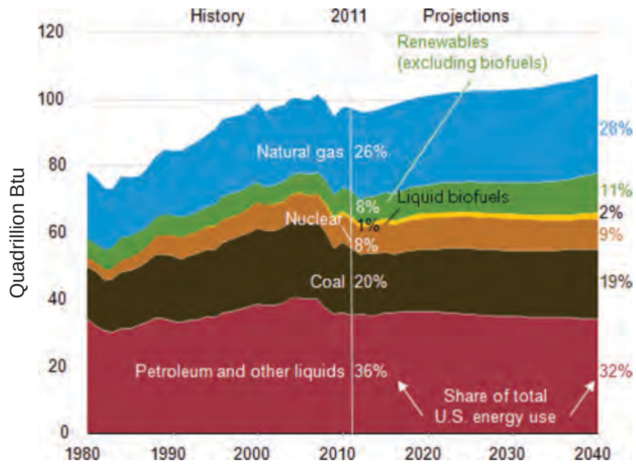


Figure 1.1. Primary energy use by fuel, 1980–2040 (quadrillion btu).[6]

that "several data collections be conducted to enhance the knowledge base" for this topic, including "siting and planning guidance for each energy technology."[7] Subject matter expert feedback for *ACRP Synthesis 28* also indicated that the impact of energy technologies on or near airport properties could extend well beyond immediate airport environs. Therefore, with this report, the ACRP has commissioned a thorough evaluation of the safety effects that energy technologies may have on the air transportation system. Based on this evaluation, the report also contains best practices, including siting guidelines, as a reference tool for addressing these safety concerns during project planning and development.

1.2 Drivers

The development of new and alternative energy resources is considered to be in the national interest supporting economic investment, environmental protection, and national security. Policies for promoting domestically produced and cleaner energy have resulted in three primary drivers behind the increased interaction between energy and aviation: (1) advancing technology, (2) decentralized energy generation, and (3) new opportunities for airports. The following sections describe these drivers in detail.

1.2.1 Advancing Technology

1.2.1.1 More Efficient and Cost-Effective Solar Energy Technologies

The solar energy industry has expanded in recent years, primarily attributable to reduced production costs that have made solar technologies more affordable for utilities and consumers alike. In addition, the widespread deployment of solar technologies has been recognized by homeowners, businesses, and government agencies as a rational economic investment to minimize the risk from volatile energy prices in the future. For example, when a homeowner installs a system on his roof, he has a high level of certainty (usually warranted by manufacturers) about how much electricity the system will produce over a 25-year period. These factors have led to widespread adoption of solar and market confidence to sustain the industry into the future, irrespective of any future breakthroughs in efficiency gains that may be achieved.

1.2.1.2 Larger and More Efficient Wind Turbines

Wind power is responsible for most of the significant progress in large-scale renewable energy generation throughout the world. No other renewable energy power generation can produce the capacity of a traditional power plant (when the wind is blowing). These successes have been achieved by building taller wind turbines composed of lighter and stronger materials to reach higher into the sky and extract a more consistent wind resource. While these taller turbines have improved the efficiency of wind energy generation, they can also create safety hazards for air navigation.

1.2.1.3 Directional Drilling and Hydraulic Fracturing

Directional drilling and hydraulic fracturing are not new technologies. However, their application in extracting natural gas efficiently from narrow shale seams has had an enormous impact on the country's fuel prices. Natural gas exploration and development has increased exponentially in specific areas of the country (the Dakotas, Texas, and Western Pennsylvania) creating new and expanding towns and economies. An oversupply in the past few years has slowed development but those natural gas resources will remain productive and activity may only slow due to increased environmental regulation. Airports in areas with shale resources are watching closely to see if energy leasing can provide an alternative revenue source (see Section 1.2.3).

1.2.2 Decentralization of the Energy Network

1.2.2.1 Distribution of New Energy Resources

New energy resources require development of generation and distribution infrastructure (e.g., power plants, power lines, and pipelines) where the resource is located rather than where populations reside. The traditional model has been to build large electricity generation facilities near population centers and deliver the fuel (e.g., natural gas, coal, oil) needed to fire

[6]EIA, "Market Trends—U.S. Energy Demand," May 2, 2013: http://www.eia.gov/forecasts/aeo/MT_energydemand.cfm#renew_natgas.
[7]Barrett, S., and P. DeVita, *ACRP Synthesis 28: Investigating Safety Impacts of Energy Technologies on Airports and Aviation*, Transportation Research Board of the National Academies, Washington, DC, 2011.

the plant. Renewable energy generation facilities must be built in geographic areas with abundant sun or wind resources, often in remote areas, and electricity must then be distributed over long distances to population centers, necessitating new electricity transmission infrastructure. For instance, many of the windiest parts of the country are in Midwestern agricultural land, which are not proximate to urban centers along the east and west coasts, nor the Great Lakes. Thus, new high-capacity electrical lines are being installed to transport wind energy from rural areas to urban centers.

Natural gas development is also tied to the specific regions where shale gas resources (also referred to as plays) have been discovered, creating economic opportunity in unexpected locations but also necessitating new distribution infrastructure to consumers in distant markets. This geographic expansion of energy development means that more airports are closer to new energy infrastructure and that airport properties themselves are likely locations for exploration.

1.2.2.2 Increased On-Site Energy Generation

Decentralization of the energy network is also capitalizing on the economic benefits of generating electricity on-site and avoiding the delivery charges associated with purchasing the electricity from the utility service provider. This is best exemplified by solar photovoltaic (PV) technology. Particularly for large, on-site energy users, the cost of building solar PV will be lower than other energy sources because all of the electricity can be used on-site and the "middle man" (the local utility) does not intercede for profit. This rationale is applicable to energy generation like solar PV at airports.

1.2.3 Alternative Airport Revenue Sources

1.2.3.1 Revenue Considerations for Different Energy Types

Airports are always looking for opportunities to increase revenue to support their aviation businesses and improve their competitive position relative to each other. New energy development provides opportunity for both new revenue and cost savings. On the revenue side, airports may be able to lease land that is not useful for other aviation or non-aviation commercial business development, due to proximity and access to valuable airport infrastructure, earning potential revenue from those leases. For airports in shale resource areas, that means learning about the business and observing whether gas prices are high enough to justify investments based on revenue potential. Other airports may be interested in leasing land for solar PV installations. In terms of cost savings, airports may also consider developing solar or even wind energy if the production price is lower than existing electricity obligations to local utilities.

1.2.3.2 Airport-Owned Resources and Private Party Leases

As discussed further in this Guidebook, about three dozen solar projects have been developed at airports and business plans for their development have generally been of two types. First, airports can capitalize, own, and construct the facilities themselves, relying on low-interest bonds or federal government grants. The risk is held entirely by the airport but the benefits of free electricity will also be realized more immediately. The second option has been to lease land to a private developer of solar energy that can take advantage of federal and state tax credits (which are unavailable to public airports). The private developer then passes the financial benefits to the airport in the form of lease payments or discounted electricity. The sophistication and diversity in structuring energy projects has also increased the number of economically viable opportunities.

1.3 Organization of the Guidebook

The Guidebook is organized functionally to serve two primary purposes: (1) to provide a detailed literature and research review of energy technologies and their relative impacts on airspace and aviation planning and (2) to provide a reference tool for planning and siting related to energy technology projects on or near airport property.

Chapter 2, "Airspace and Airports" first defines airspace from the perspective of aviation users. Then, an overview of FAA management of the National Airspace System (NAS) is provided, including its regulatory interaction with airports. Later, Chapter 2 covers plans for operational improvements within the NAS (notably the Next Generation Air Transportation System, or NextGen). Finally, an analysis of aviation accidents and incidents related to energy technologies is presented, providing a context for understanding the impacts of new energy technology projects and opportunities for planning process improvements.

Chapter 3, "Energy Technologies and Aviation Safety Impacts" is divided into several sub-sections pertaining to different energy technology types, including Solar, Wind, Oil and Gas Drilling, Steam Turbine Power Plants, and Electricity Transmission. Each technology sub-section provides an overview of recent industry trends as well as recent developments in government regulations, and relevant information for aviation projects. After the overview content, unique technological issues are explained, particularly in conjunction with projects affecting airspace and airports. Specific project challenges are then illustrated through various case studies. Finally, lessons learned through experience and research is presented to assist planning for future endeavors and improve project success for multiple stakeholders.

Chapter 4, "Guidance" is also organized by energy technology, digesting lessons learned from experience to develop specific project siting and planning guidance that can assist airport managers and planners, as well as energy professionals. Chapter 4 is intended as a reference tool for project managers and stakeholders. It is better understood in the context of Chapters 2 and 3 but, after initial review, can provide a stand-alone resource.

In conclusion, **Chapter 5, "Moving Forward"** restates the primary result of the research conducted and outlines ongoing research related to aviation safety and energy technologies, suggested areas for additional research, and current progress in the government regulatory framework as well as issues that deserve additional focus.

1.4 Audience

This Guidebook is intended for review and use by airport managers and planners, aviation professionals, and energy professionals. Airport managers and planners will find the Guidebook helpful to understand the context of energy project impacts on aviation use, provide a basic understanding of various energy technologies, and improve information to assess on- and off-airport project proposals. Aviation professionals will likely derive value from this Guidebook to assist airports and energy firms in assessing proposed projects and implementing them with minimal aviation impact. Finally, energy professionals will benefit from the information in this Guidebook for understanding aviation issues and improving project siting compatibility and early stage project development.

It is suggested that all readers review the entire Guidebook for a more complete understanding of the confluence of aviation and energy technologies from the perspective of safety issues. In addition, all readers are encouraged to utilize Chapter 4, "Guidance" for assistance in future project review and development.

CHAPTER 2

Airspace and Airports

The U.S. National Airspace System (NAS) is a public good, administered by the FAA to ensure safety, while also accommodating various user groups, including scheduled air carriers (passenger and cargo), business aviation (air taxis and on-demand commuters), general aviation (private operators), and military. However, the NAS is also a finite resource in the sense that its capacity is fixed, limited by international airspace boundaries but also by the operational capabilities of its airports (i.e., the number of arrivals and departures that airports can collectively support). As a finite resource, aircraft operators compete for scheduling and routing priorities. However, contention over airspace use also occurs closer to ground level, where non-aviation activities may impede safe use of the airspace above. Structures rising above a certain height may be considered obstructions to airspace use (e.g., wind turbines). Land use on or near airports may also be considered harmful to airport operations or airspace use (e.g., oil and gas drilling equipment, glare from solar panels, thermal plumes from electricity generating facilities).

Energy technologies can function effectively in low-altitude airspace environments and on or near airport property, so long as projects are sited and implemented safely. The FAA has regulatory authority to ensure that energy projects abide by relevant legislation and adhere to certain evaluation criteria. Thus, project stakeholders must be familiar with relevant review processes that may determine approval of their projects. Moreover, as many energy technologies have evolved in recent years and installation of certain technologies (e.g., natural gas, wind, solar) has increased exponentially, the FAA is continually updating review requirements, so stakeholders must be aware of recent developments to ensure compliance.

This chapter provides an overview of FAA management of the NAS, including infrastructure used to support flight operations. Critically, the FAA's plans to implement the Next Generation Air Transportation System (NextGen) will result in significant technological and procedural advances for in-flight operations, so this chapter also provides an overview of key NextGen operational improvements as they may relate to energy technologies. The remainder of the chapter then highlights fundamental legislation and regulatory requirements intended to ensure flight safety, followed by an overview of applicable evaluation procedures and criteria that would be required for approval of energy technology installations and operation in the aviation environment. Chapter 3 provides additional detail about the specific regulatory requirements and evaluation process for each energy technology examined in this Guidebook.

2.1 Governing U.S. Airspace

The *Federal Aviation Act of 1958* delegates various responsibilities to the FAA including control over the use of the nation's navigable airspace and regulation of civil and military operations in that airspace in the interests of safety and efficiency.[8] Within the U.S. NAS, the FAA manages aircraft takeoffs, landings and the flow of aircraft between airports through an infrastructure of air traffic control and navigation facilities; people (e.g., air traffic controllers, maintenance personnel); and technology (e.g., radar, communications equipment).

The U.S. NAS is one of the most complex aviation networks in the world and when the FAA proposes changes to its design and operation, four principles must be preserved:

1. Maintain or improve system safety.
2. Increase system flexibility, predictability, and access.
3. Improve efficiency and reduce delays.
4. Support evolution of emerging technologies.

As a public service, the FAA provides the network of infrastructure, people, and technology that is used to monitor, guide, and direct aircraft along routes within the NAS. This service is known collectively as air traffic control (ATC). Inside

[8] U.S. Code (U.S.C.), Title 49, Section 40101(d)4.

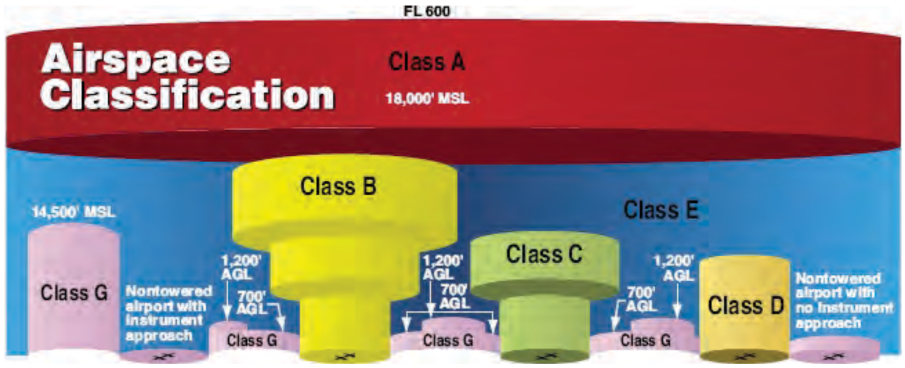


Figure 2.1. Types of controlled airspace.[11]

the FAA, the Air Traffic Organization (ATO) is responsible for managing day-to-day ATC operations, including the maintenance of safe separation distances between aircraft and the efficient flow of air traffic with as little delay as possible while maintaining safety standards. Additionally, the FAA Airports organization (ARP) is responsible for maintaining a safe and efficient national airport system, including airport safety programs and development of standards for airport design and construction. With respect to energy technology projects on or near airports, or with potential impacts on airspace use, ATO and ARP conduct evaluations to ensure compliance with certain safety requirements. Other offices within the FAA may also be involved in different components of project review.

2.2 Airspace Operations

In order to ensure the safety of aircraft operating to and from airports, the FAA has established procedures for aircraft operations based on the complexity or density of aircraft movements, operation type, safety requirements, and the national and public interest. The FAA Aeronautical Information Manual (AIM) organizes the national airspace into four categories: (1) controlled, (2) uncontrolled, (3) special use, and (4) other.[9] Controlled airspace includes the airspace around busy airports, along aircraft routes, and above 18,000 ft. It is further divided into five classes (A, B, C, D, and E), as depicted in Figure 2.1. Each class is distinguished by different altitude and spatial dimensions and by the types of aircraft operations within the airspace following different rules. Uncontrolled airspace (Class G) includes the airspace that the FAA has not designated as Class A, B, C, D, or E airspace.[10] Special use airspace includes restricted, prohibited, warning, and alert areas, as well as military operations areas (MOAs). The energy technologies examined in this Guidebook can be installed in a variety of geographic areas, subject to different airspace classifications, including controlled airspace on or near airport property or uncontrolled airspace in remote areas, potentially near an airfield without ATC service.

Aircraft operate under two distinct categories of flight rules: Visual Flight Rules (VFR) and Instrument Flight Rules (IFR).[12] These flight rules generally correspond to two categories of weather conditions: Visual Meteorological Conditions (VMC) and Instrument Meteorological Conditions (IMC). VMC generally exist during fair to good weather, when good visibility conditions exist. IMC occur during periods when visibility falls to less than 3 statute miles or the cloud ceiling[13] drops to lower than 1,000 ft. Correspondingly, under VFR a pilot is responsible to "see and avoid" to maintain safe separation from other aircraft and obstacles. IFR procedures are designed for use when separation from other aircraft and terrain is maintained by cockpit instrument reference or radar. Pilots must follow IFR during IMC. Regardless of weather conditions, however, the majority of commercial air traffic operates under IFR.

Standard instrument procedures define routes along which aircraft operate. For aircraft operating under IFR, air traffic controllers maintain separation by monitoring and directing pilots of aircraft following standard instrument procedures. Controllers monitor the aircraft routes, altitudes, and airspeeds using various sensors (e.g., radar and satellites). Effectively, this system of procedures defines the routes along which IFR aircraft operate. Procedures are published in order to ensure safe clearance from obstacles and adequate reception of communications between pilots and air traffic control.

"Conventional" standard instrument procedures rely on verbal instructions from controllers to the pilot, in conjunction

[9]U.S. Federal Aviation Administration (FAA), "Aeronautical Information Manual: Official Guide to Basic Flight Information and ATC Procedures," August 22, 2013: http://www.faa.gov/air_traffic/publications/atpubs/aim/index.htm.

[10]FAA, Order JO7400.2J, "Procedures for Handling Airspace Matters, Part 4 Terminal and En Route Airspace," Change 2.

[11]FAA, "Course Name: ALC-42: Airspace, Special Use Airspace and TFRs," https://www.faasafety.gov/gslac/ALC/course_content.aspx?cID=42&sID=505&preview=true, U.S. Federal Aviation Administration.

[12]Code of Federal Regulations (CFR), Title 14, Part 91.

[13]Ceiling: the distance from the ground to the bottom layer of clouds, defined as the point where the clouds cover more than 50 percent of the sky.

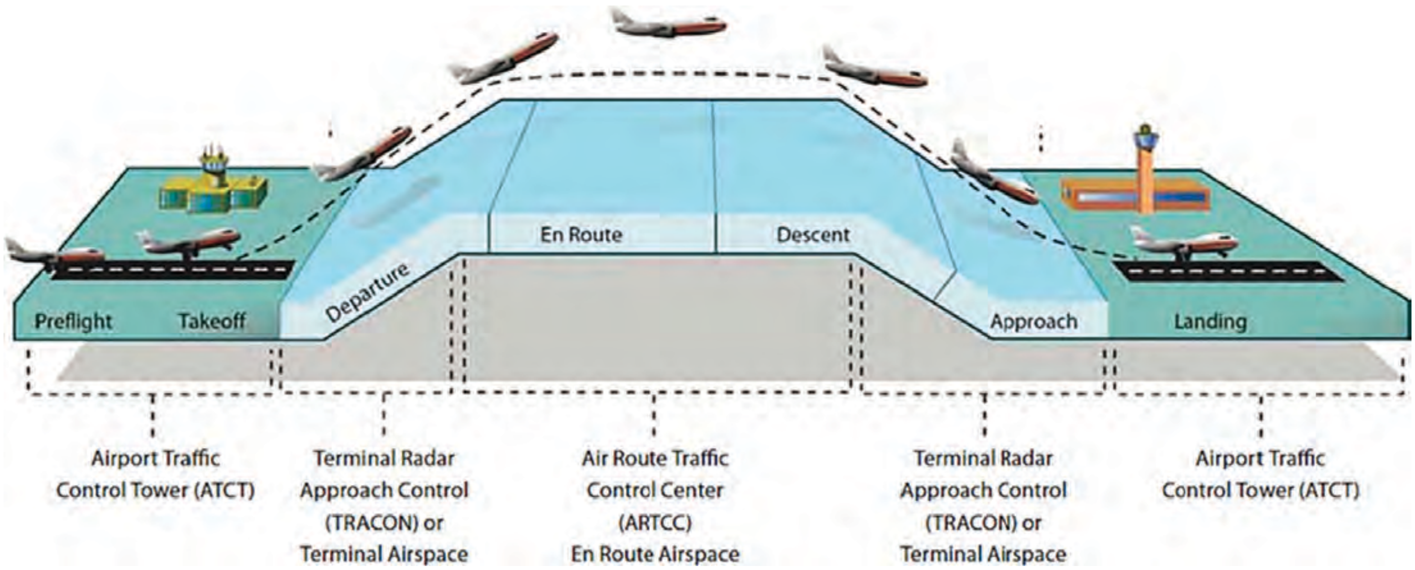


Figure 2.2. Phases of flight.

with instrument guidance transmitted from ground-based Navigational Aids (NAVAIDs). The aircraft flies above the NAVAIDs along a point-to-point route while the aircraft cockpit instruments receive instructions via data communication with the NAVAIDs below. Recently, FAA has begun to employ innovative technologies to enhance routes defined by standard instrument procedures. Area Navigation (RNAV) is one such technology, which enables RNAV-equipped aircraft to fly more precise and efficient routes. RNAV procedures are based on instrument guidance transmitted from a network of ground-based NAVAIDs operating in concert, as well as space-based navigational aids that use Global Positioning System (GPS) technology.

To understand the types of potential impacts that energy technologies may have on aircraft and ATC operations within airspace, it is useful to understand the flow of an aircraft through the NAS, from one airport to the next. After departing its origin airport, an aircraft passes through multiple airspace types, controlled by multiple ATC service facilities, using various NAVAIDs (e.g., radar), finally approaching, and landing at its destination airport. See Figure 2.2 for a visual depiction of these phases of flight.

Control of a typical aircraft flight begins with a controller in an air traffic control tower (ATCT) issuing departure clearance instruction to the pilot. ATCTs control departing and arriving flights that are normally within a few miles of the airport as well as aircraft on the ground at the airport. ATCTs normally use visual contact to track arriving and departing aircraft and those on the ground. Due to this requirement for visual contact, the FAA evaluates potential obstructions on or near airport property for safety implications. As discussed in Chapter 3, certain energy technologies are capable of impeding ATC visual contact, including physical obstructions (e.g., wind turbines) or non-physical air safety hazards (e.g., solar panel glare, visible plumes).

Once the aircraft leaves the vicinity of the airport, a Terminal Radar Approach Control (TRACON) facility normally assumes responsibility for guiding the flight. Controllers in a TRACON use short-range radar to identify and track aircraft out to an approximate distance of 50 miles from the airport. Airspace assigned to a TRACON is divided into sectors.[14] A controller, or team of controllers, manages the safe, orderly, and expeditious flow of air traffic within the sector. As aircraft move through the TRACON-controlled airspace, management responsibility is transferred and the aircraft is "handed off" from a controller in the previous sector to the controller in the new sector. As with ATCT visual guidance, the reliance upon ground-based NAVAIDs and radio communications in the terminal area necessitates that sources of transmission interference must be cleared or mitigated, including wind turbines and other energy technologies.

As the aircraft moves further from the airport and climbs to higher cruising altitudes, control is passed to an Air Route Traffic Control Center (ARTCC), a much larger airspace than a TRACON. Controllers in an ARTCC, or "Center," use long-range radar to identify and track aircraft. In remote areas without proximity to an ATCT or TRACON, the Center also assumes responsibilities that would otherwise be designated to airport and terminal area controllers. As the aircraft proceeds toward its destination, control is typically transferred to succeeding Centers along the flight route and then back to a TRACON and ATCT as the aircraft approaches its destination airport. Again, similar to reliance upon short-range radar in

[14] Sector: a portion of positively controlled airspace having defined geographic and altitude boundaries.

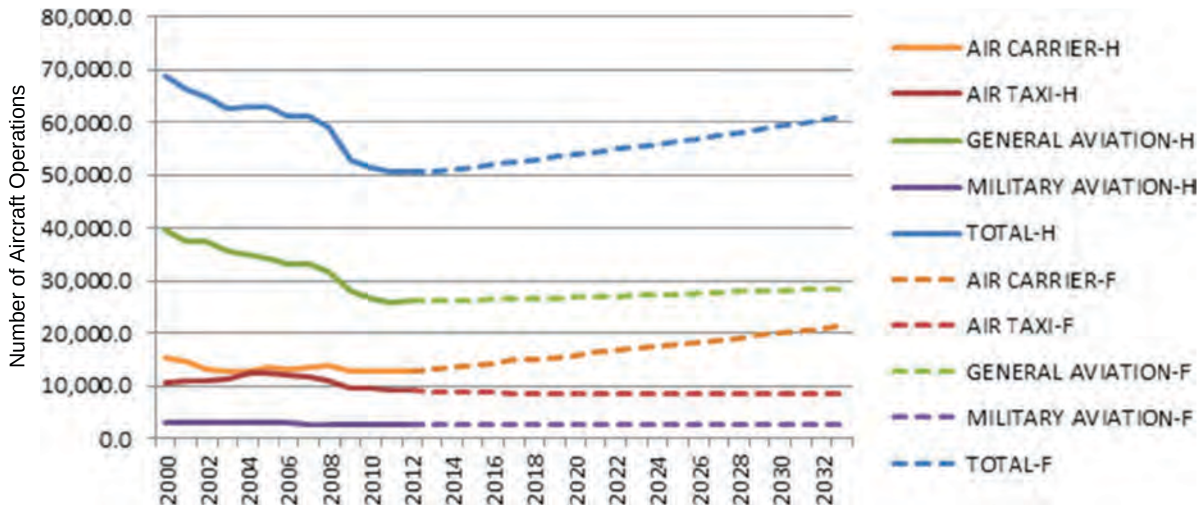


Figure 2.3. Historical and forecast of aircraft operations (thousands).

the terminal area, the Centers' reliance upon long-range radar necessitates the removal or mitigation of all obstructions of air safety hazards near NAVAIDs, including wind turbines and other energy technologies.

This phases of flight scenario applies to aircraft operating in a controlled airspace environment. However, many aircraft operate in non-controlled airspace, either for the entire duration of the flight or involving departure/arrival in non-controlled airspace. The ATC facilities described in this section may not be applicable for aircraft operating in a non-controlled environment.

2.3 Airspace Users

As a public resource, many airspace user groups share the NAS, each with different operating requirements and/or business models. The FAA accommodates these user groups in daily operations by balancing scheduled operations with on-demand requests, as well as prioritizing military use. The following terms are used to distinguish among these user groups:

- Air carriers refer to airlines that offer scheduled air service for passengers and/or cargo.
- Air taxi/commuter refers to commercial operations, usually using small aircraft, for on-demand flights, often for short distances.
- General aviation (GA) refers to all civil aviation operations other than scheduled air services and non-scheduled air transport operations for remuneration or hire.
- Military aviation refers to the use of aircraft and other flying machines for the purposes of conducting or enabling warfare, including national airlift (i.e., cargo) capacity to provide logistical supply to forces stationed in a theater of battle or along a front.

Figure 2.3 displays the historical and forecast aircraft operations in the United States based on data from the FAA "Aerospace Forecast: Fiscal Years 2013–2033."[15] The FAA estimates total aircraft operations at more than 60 million per year by 2033. GA operations have declined significantly since year 2000 and the FAA estimates they will stabilize but remain lower than year 2000 levels. In contrast, the FAA estimates air traffic demand for air carriers to increase continuously from 2013 to 2033, which could be due to population growth as well as the growing demand for travel.

In addition to the airspace users described above, demand for operation Unmanned Aircraft Systems (UAS) has increased in recent years. UAS were initially developed for military purposes but have demonstrated potential for valuable commercial and civil applications. UAS range in size from less than 1 lb. to several tons. Rapid demand growth for UAS and the broad range of design types are adding complexity to the NAS and raising potential safety issues. Several U.S. government agencies at the federal, state, and local levels have stated intentions to utilize UAS for official operations, including the use of small UAS for "first responder" missions.

The increased demand for civilian use of UAS in the NAS will significantly affect airspace usage, regulation, and air traffic control. Therefore, the FAA is currently developing rules for incorporating UAS into NAS operations. Approved by Congress in February 2012, the "FAA Modernization and Reform Act of 2012" required the FAA to streamline the process for public agencies to safely fly UAS in the nation's airspace. In response to this legislation, the FAA created a new UAS Integration office to incorporate civil and public

[15]FAA, "FAA Aerospace Forecast: Fiscal Years 2013–2033": http://www.faa.gov/about/office_org/headquarters_offices/apl/aviation_forecasts/aerospace_forecasts/2013-2033/media/2013_Forecast.pdf.

Pilots and Airspace Hazards

The FAA, through its Aeronautical Information Management Office, manages PilotWeb, which provides information to assist pilots and aircrews for flight planning and familiarization. It may be used in conjunction with other pre-flight information sources needed to satisfy all the requirements of Code of Federal Regulations, Title 14, Section 91.103 and is not to be considered as a sole source of information to meet all pre-flight action. PilotWeb includes Notice to Airmen (NOTAMs), which is "a notice containing information concerning the establishment, condition, or change in any component (facility, service, or procedure of, or hazard in the National Airspace System) the timely knowledge of which is essential to personnel concerned with flight operations." Pilots are initially informed that "the main references for changes to the NAS are the Aeronautical Charts and the Airport/Facility Directories (AFD) and that most changes to the NAS meeting NOTAM criteria are known sufficiently in advance to be carried in these publications. When this cannot be done, changes are carried in the Notices to Airmen publication (NTAP) and/or the Service A telecommunications system as a NOTAM D item."

use of UAS in NAS operations and resolve related safety issues.[16] For example, certain UAS may include extensive use of low-altitude airspace, necessitating that the FAA modify ATC procedures to accommodate UAS while ensuring safe operations of other aircraft through that airspace.

Different airspace users and aircraft types may interact with energy technologies in specific ways. To illustrate, air carriers with advanced avionics may rely more on instrument procedures for approach and landing procedures, even near the airport, whereas GA may be more visually dependent. In that case, a cluster of solar panels causing glare may be a significant hazard for GA pilots but only minimally intrusive for a commercial pilot. As another example, UAS operations at low altitudes near wind turbines may result in impeded operations and possibly even collisions. These sorts of potential issues must be taken into account when siting and implementing energy projects in the airspace and airport environments.

[16]FAA, "FAA Makes Progress with UAS Integration," May 14, 2012: http://www.faa.gov/news/updates/?newsId=68004.

2.4 NextGen Implementation

Approved by Congress in 2003, the "Vision 100—Century of Aviation Reauthorization Act" (P.L. 108-176) charged the FAA with planning and implementing the Next Generation Air Transportation System (NextGen), with the purpose of modernizing the NAS in several critical functional areas through 2025. The primary goal of NextGen, as stated in Vision 100, is to "improve the level of safety, security, efficiency, quality, and affordability of the National Airspace System and aviation services." In general terms, NextGen "includes satellite navigation and control of aircraft, advanced digital communications, enhanced connectivity between all components of the national air transportation system, and a much larger role for advanced automation capabilities in the control of aircraft."[17] NextGen is composed of nine capability areas or functional groupings of new procedures for ATC and aircraft to operate within the NAS, new policies to set planning and investment priorities, advances in technology and automation, and incentives for airspace users to adopt that technology:[18]

1. **Collaborative Capacity Management** improves the ability to balance system demand and allocate airport and airspace in real time, through improved coordination among ATC and airspace users and use of improved automation tools.
2. **Collaborative Flow Contingency Management** improves the management of major air traffic flows (e.g., during severe weather conditions) while minimizing overall NAS impact, through improved coordination and stakeholder response.
3. **Efficient Trajectory Management** provides the ability to assign and modify flight routes that minimize the frequency and complexity of aircraft conflicts within an air traffic flow, by incorporating real-time information about other aircraft and overall system usage.
4. **Flexible Separation Management** aircraft are safely separated from other aircraft, vehicles, protected airspace, terrain, weather, etc., by predicting conflicts and identifying resolutions (e.g., course, speed, altitude, etc.) in real time.
5. **Integrated NextGen Information** provides ATC and airspace users critical information (e.g., weather, surveillance, aeronautical, flight planning, and location data) to improve awareness and decision making through use of an Internet-based data-sharing network for authorized personnel.
6. **Air Transportation Security** improves the ability to respond to security situations with appropriate resources

[17]Joint Planning and Development Office (JPDO), "NextGen Topics": http://www.jpdo.gov/Nextgen_Topics.asp.
[18]Ibid.

and tactics, while also minimizing impacts on civil liberties, and airspace operations, through use of improved risk assessment and risk management techniques.

7. **Improved Environmental Performance** identifies and attempts to prevent or proactively address environmental impacts as consistent with national and international regulations, by incorporating environmental analysis into operations, policies, and automated decision support tools, as well as adoption of sustainable energy technologies.
8. **Improved Safety Operations** integrates safety considerations in all NAS operations, with an enhanced focus on information sharing and coordination, improved safety risk analysis, incorporation of safety information into automated decision support tools, improved awareness of safety vulnerabilities, and consistent application of safety techniques.
9. **Flexible Airport Facility and Ramp Operations** provides the ability to reallocate or reconfigure the gates and other airport resources (e.g., maintenance, refueling, and cargo equipment) to accommodate real-time operational requirements through infrastructure upgrades; improved information sharing among stakeholders (e.g., airports, service providers, ATC, security organizations, and airspace users); and automated planning tools.

The FAA is currently implementing many of NextGen' s early stage operational improvements, including infrastructure upgrades and procedural changes that will enable more advanced, late-stage developments by 2025. As presented in the FAA's "NextGen Implementation Plan" for 2013, the three major thrusts of current NextGen activities are installation of Automatic Dependent Surveillance-Broadcast (ADS-B) technologies, incorporation of Performance-Based Navigation (PBN) technologies and related procedures, and coordinated implementation in key metropolitan areas with multiple airports and significant congestion ("Metroplexes").[19]

Automatic Dependent Surveillance-Broadcast (ADS-B) is a "satellite-based successor to radar [that] enables more accurate aircraft tracking" [20] through use of GPS technology that is transmitted from (or broadcasted from) aircraft to ATC facilities, providing a more complete and instantaneously updated picture of the NAS with precise location and timing information. ADS-B information is displayed to pilots and controllers in a manner similar to radar data, but the displays update in real time and are not degraded by obstructive terrain or long distances. Furthermore, as technology platforms continue to develop, ADS-B will enable automated weather and flight management services by disseminating location data and flight characteristics to decision support tools.[21] The FAA has already installed more than 500 ADS-B radio stations in the U.S., with coverage along the East, West, and Gulf coasts, and along the Canadian border. The ultimate benefits of ADS-B will be realized with maximum equipage among airspace users, so the FAA has issued a plan to require full ADS-B equipage by 2020 for access to ADS-B designated airspace.[22] The FAA is collaborating with air carriers and airports to obtain ADS-B operational data in order to validate its benefits and encourage equipage.[23]

Performance-Based Navigation (PBN) is a framework for defining performance requirements in "navigation specifications," which can be applied to an air traffic route, instrument procedure, or defined airspace. In essence, it "enables aircraft to fly more direct routes, [increasing] airspace efficiency."[24] PBN provides a basis for the design and implementation of automated navigation along flight paths, as well as for airspace design and obstacle clearance. Once a required performance level is established, an aircraft's own capability determines whether it can safely achieve the specified performance and qualify for the operation. The two main components of the PBN framework are Area Navigation (RNAV) and Required Navigation Performance (RNP). "RNAV enables aircraft to fly on any desired flight path within the coverage of ground- or spaced-based navigation aids, or within the limits of the capability of aircraft self-contained systems, or a combination of both capabilities."[25] RNP is essentially RNAV with the addition of an onboard capability to monitor an aircraft's navigation performance and inform the crew if the requirement is not met during an operation.[26] Several NextGen capabilities, as described above, are dependent upon the implementation of RNAV and RNP technologies. For that reason, the FAA has begun to aggressively publish PBN routes and procedures, with over 800 published in 2012.[27]

The precision, accuracy and reliability of PBN flight paths (especially RNP) gives ATC the ability to sequence air traffic predictably so that an advanced arrival procedure, called an Optimized Profile Descent (OPD), can be accommodated without interrupting conventional operations (illustrated in Figure 2.4, in comparison to an Instrument Landing System

[19]FAA, "NextGen Implementation Plan, 2013": http://www.faa.gov/nextgen/implementation/.
[20]Ibid.
[21]FAA, "ADS-B General Information," January 12, 2012: http://www.faa.gov/nextgen/implementation/programs/adsb/general/.
[22]FAA, "ADS-B Frequently Asked Questions (FAQs)," May 13, 2013: http://www.faa.gov/nextgen/implementation/programs/adsb/faq/.
[23]FAA, "ADS-B General Information," January 12, 2012: http://www.faa.gov/nextgen/implementation/programs/adsb/general/.
[24]FAA, "NextGen Implementation Plan, 2013": http://www.faa.gov/nextgen/implementation/.
[25]FAA, "Fact Sheet—NextGen Goal: Performance-Based Navigation," March 12, 2010: http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=10856.
[26]Ibid.
[27]FAA, "NextGen Implementation Plan, 2013": http://www.faa.gov/nextgen/implementation/.

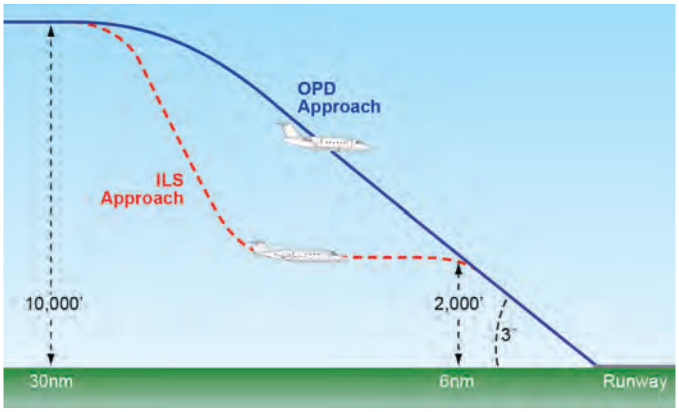


Figure 2.4. Optimized profile descent.

[ILS] approach). An OPD is a procedure in which the aircraft's flight management system (FMS) facilitates a continuous descent from the top of descent to touchdown, without level-off (i.e., step-down) segments. The FMS chooses the optimum point to begin an aircraft's descent to landing and then selects the lowest possible thrust setting (often flight idle) to keep the aircraft on a desired descent profile, adjusting for wind, temperature, and other flight variables throughout the descent. This reduces carbon dioxide (CO_2) emissions and fuel burn.

In order to achieve immediate efficiency gains in congested metropolitan areas, the FAA has instituted the Optimization of Airspace & Procedures in the Metroplex (OAPM) initiative. OAPM improvements are designed to streamline arrival and departure traffic by implementing PBN procedures and other airspace design improvements.[28] "By optimizing airspace and procedures in the Metroplex, the FAA provides solutions on a regional scale, rather than focusing on a single airport or set of procedures."[29] "Seven active Metroplex sites are in or entering the design and evaluation phases." The first three sites (Washington, D.C., North Texas, and Houston) were intended to be in implementation by the end of 2013"[30] but are now expected in early 2014.

Two additional components of NextGen that are critical in achieving early-stage operational improvements are Airport Surface Detection Equipment—Model X (ASDE-X) and Data Communications (Data Comm). "ASDE-X is a surveillance system that uses radar and satellite technology to help controllers track the movement of aircraft and vehicles on the airport surface [e.g., runways and taxiways] . . . [which] helps controllers make better decisions that support the safety and efficiency of ground surface movements."[31] The concept of Data Comm itself is not an operational improvement, but the replacement of the current analog voice system to advanced digital communication technologies is a fundamental element of NextGen, enabling more efficient data transmission and supporting system automation for both aircraft and air traffic control.[32]

The fundamental changes NextGen will make to NAS operations may alter the context for how the aviation safety impacts of energy technologies are evaluated. Technologies that may be obstructions or aviation safety hazards today may be largely avoidable in the future as aircraft capabilities change and airspace use becomes more flexible. The following scenarios bear examination during NextGen implementation:

- With reduced separation between aircraft and condensed air traffic flows, an energy technology installation near new flight paths may need to be re-evaluated as obstructions or air safety hazards; alternatively, increased flexibility and precision under NextGen could make re-routing air traffic a safe distance away from the installation an easier solution.
- Increased reliance on PBN technologies for approach and landing will likely reduce use of VFR at many airports, mitigating glare issues from solar panels installations on pilots, and potentially providing greater flexibility for siting solar projects close to airports.
- The effect of wind turbulence and signal disruption will be reduced with increased use of ADS-B and Data Comm, which could lead to fewer design constraints for wind turbines, augmented farm densities, and an increase in turbine height, potentially leading to increased energy production.
- NextGen capabilities like PBN and ASDE-X will lead to several operational changes in terminal airspace and on the airport surface, potentially necessitating revision of Obstruction Height Zone requirements under 14 CFR Part 77.

In sum, NextGen implementation will raise additional questions on the topic of energy technologies and aviation safety, but it will also likely offer innovative solutions to problems we are just beginning to understand.

2.5 Protecting Airspace through Airport and Land Use Planning

The FAA is responsible for guarding the NAS against intrusions that may impede safe use of airspace and airport resources. As stated previously, the FAA regulates such intrusions as obstructions (physical) or aviation safety hazards

[28]FAA, "NextGen Implementation Plan, 2013": http://www.faa.gov/nextgen/implementation/.
[29]ATAC, "OAPM Environmental—OAPM": http://oapmenvironmental.com/oapm.html.
[30]FAA, "NextGen Implementation Plan, 2013": http://www.faa.gov/nextgen/implementation/.
[31]FAA, "A Better View of Operations at World's Busiest Airport," August 8, 2013: http://www.faa.gov/nextgen/snapshots/slides/?slide=20.
[32]FAA, "Program Overview—About Data Comm," June 23, 2008: http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/techops/atc_comms_services/datacomm/general/.

(non-physical). The FAA's ability to regulate obstruction intrusions into the NAS is extremely limited, as it is restricted to monitoring the erection of obstructions (i.e., charting) and mitigating hazards by modifying aviation procedures. The FAA's ability to enforce on-airport land use is based entirely on contractually based grant assurances, rather than regulations. However, off-airport land use regulations are largely at the discretion of local government. This lack of regulatory authority outside of airport boundaries is a fundamental reason for the publication of the findings in this Guidebook.

One of the primary means of protecting airspace on airport property is through the preparation of Airport Layout Plans (ALPs) and Master Plans. The FAA and airports utilize Advisory Circular (AC) 150-5300-13A, "Airport Design," to guide development on airport property and prepare the ALPs. For land uses off airport property, the FAA must work with airports and their local communities to achieve conformance of existing and proposed natural and developed features to airspace protection criteria. Because protection criteria are well defined for physical penetrations of airspace and less so for non-physical impacts, the criteria and guidance for land use planning can vary among project types.

The following are examples of legislative and regulatory guidance to protect airspace and airport resources from unsafe intrusion:

- Runway Protection Zones, as defined by FAA Advisory Circular (AC) 150-5300-13A, *Airport Design.*
- Obstruction Height Zones, as defined by 14 CFR Part 77 and local zoning ordinances.
- The United States Standard for Terminal Instrument Procedures (TERPS), as defined by FAA Order 8260.3B.
- Land use controls, as defined by local zoning ordinances (new Land Use Compatibility AC, 150/5190-4A).

Much of the airport property is limited for development based on height of structure and distance from airport facilities (see Obstruction Height Zones and TERPS). The Runway Protection Zones (RPZs), however, are specific areas at each end of a runway that are limited for development based on land use type. While the criteria noted in FAA AC 150/5300-13A, *Airport Design*, states that the FAA requires that all objects must be cleared from the RPZ, some uses are permitted provided they do not attract wildlife, are outside of the runway object free area (OFA), and do not interfere with navigational aids. In September 2012, the FAA issued a memorandum entitled "Interim Guidance on Land Uses in the Runway Protection Zone (RPZ)" to provide enhanced clarity on FAA policy. The Interim Guidance memo states that certain new or modified land uses in the RPZ require coordination with the FAA Office of Airport Planning and Programming (APP-400). Included in the list of land uses is "above-ground utility infrastructure (i.e., electrical substations), including any type of solar panel installations."

2.5.1 Obstruction Height Zones

Obstruction Height Zones are used to limit and regulate the height of objects that could otherwise cause a loss of navigable airspace, particularly within the vicinity of an airport. Local municipalities often regulate the height of buildings and other structures by establishing zoning ordinances, based on 14 CFR Part 77. This regulation (abbreviated as Federal Aviation Regulations (FAR) Part 77) establishes standards and notification requirements for objects affecting navigable airspace. The regulations define a set of imaginary surfaces in the airspace around an airport. Any object (including structures, trees, movable objects, and even the ground itself) that penetrates one of the airspace surfaces is considered an obstruction. Wind turbines and power plant stack towers are examples of energy technologies that would require evaluation under Part 77 whereas solar panels often are not tall enough to impinge into airspace (see Figure 2.5). There are other parts of the Airport Design AC that also affect location of structures as obstructions on airport property including proximity to NAVAIDs (and potential for interference) and potential effect on air traffic control visibility.

Part 77 functions chiefly as a device for notifying the FAA about proposed construction near an airport so that the agency can assess whether the object would be a hazard to flight. Project proponents provide notification to the FAA using FAA Form 7460-1, *Notice of Proposed Construction or Alteration.* Receipt of the notice enables the FAA to evaluate the effect of the proposed object on air navigation and chart the object or take other appropriate action to ensure continued safety. The FAA evaluates height concerns for land uses within the following five surface area classifications: (1) Approach, (2) Transitional, (3) Horizontal, (4) Conical, and (5) Departure. Part 77 specifies height and slope restrictions based on the surface area type. A graphical illustration of the Part 77 surfaces surrounding airport runways is provided in Figure 2.6. Additionally, any proposed object with a height of more than 200 ft. requires notification, regardless of proximity to an airport. Refer to Part 77 for exceptions and additional reporting requirements.

2.5.2 TERPS

The U.S. Standard for Terminal Instrument Procedures (TERPS) defines another set of airspace protection surfaces for airports that utilize standard instrument procedures. The FAA uses these surfaces to design instrument procedures. In most cases, TERPS surfaces are higher than those of Federal Aviation Regulations (FAR) Part 77 and less restrictive on the heights of objects. The FAA publishes (and regularly updates) charts showing the approved instrument approach and departure procedures for individual airports. These charts define where aircraft must fly to remain clear of obstructions near the airport. Any new object that penetrates one of the surfaces would require a modification to the procedure. The

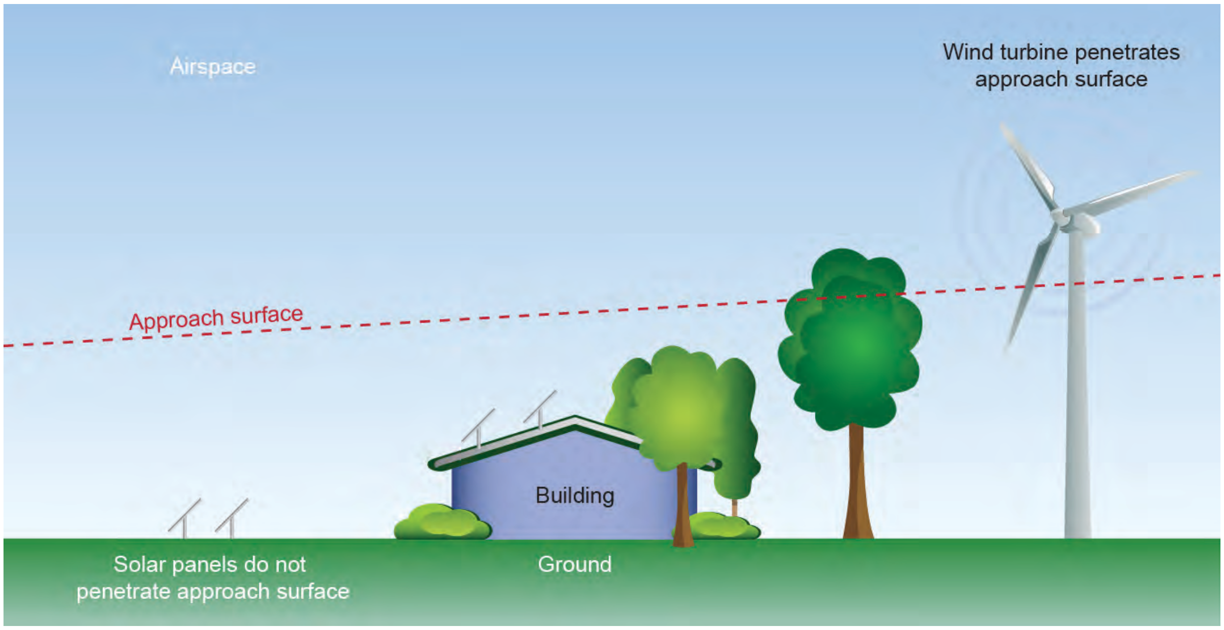


Figure 2.5. Examples of structures that may impinge on airspace.

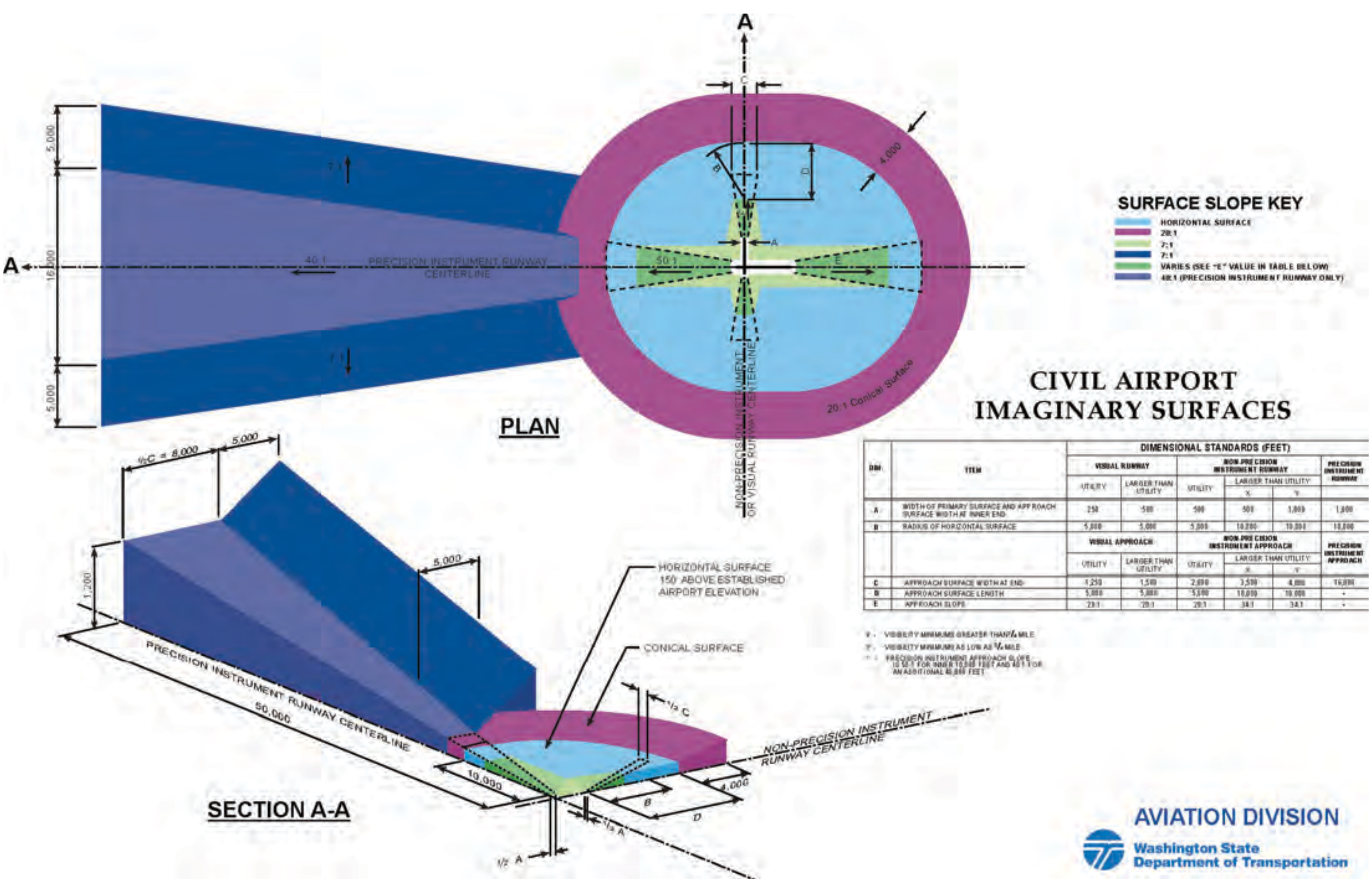


Figure 2.6. Civil airport imaginary surfaces.

Table 2.1. FAA divisions and evaluation responsibility for aeronautical studies.

Office	Evaluation Responsibility
Air Traffic Obstruction Evaluation Office (AT OES)	Part 77 requirements
Air Traffic Operation Service Group (AT OSG)	Coordination with air traffic control to identify any operation impacts
Technical Operations (Tech Ops)	Impact of NAVAIDs, electromagnetic and line-of-sight shadow interferences
Flight Standards (FS)	Review of proposals to determine the safety of aeronautical operations
Flight Procedures (FP)	Review of proposals to determine impacts on instrument procedures
Airports (ARP)	Identify impacts on different airport operations characteristics

implementation of RNP technologies and procedures under NextGen will result in narrower TERPS flight corridors and improved obstacle clearance, resulting in improved performance and safety.

Land use controls are also necessary to ensure that certain ground-based activities do not compromise aviation safety. The public safety element of aviation compatible land use is established through zoning to limit certain activities that pose risks to aircraft operations. Potential risks to public health and safety are minimized by regulating land use near airports with the following characteristics:

- Congregation of people.
- Presence of flammable, explosive, or hazardous material.
- Presence of intervening structures, objects, excavations or bodies of water in the immediate area of runways.
- Emission of smoke, light, or other phenomenon that could obscure the pilot's vision during take-off and landing or create unstable air through which the aircraft must pass.
- Unshielded electromagnetic or high energy device emissions that could interfere with ground or airborne electronic systems used for aircraft flight control or navigation.
- Attracting birds or animals in areas where aircraft could strike them during take-off or landing either in flight or on the runway.

Land use controls may establish specific building size limitations, population density limitations, reflectivity and emission controls, materials use prohibitions and storage requirements, or land slope/grading limitations. Most controls are only necessary in close proximity to airport runways. Criteria defining land use characteristics that can cause visual or electronic hazards to flight are qualitative in nature and the FAA has not yet set precise standards. In general, visual hazards to flight include sources of dust, steam (e.g., thermal plumes), smoke, or glare (e.g., solar panels) that can impair pilot visibility, as well as distracting lights that can be confusing for the airport. Electronic hazards cause interference with aircraft communications or navigation (e.g., wind turbines).

The FAA is currently developing a new Land Use Compatibility AC (AC 150/5190-4A) which is scheduled for release in mid-2014. This new guidance will provide local governments and airport owners a comprehensive approach to maximizing safety, economic development, and quality of life.

While research for this Guidebook shows that the standards of review are inconsistent between physical and non-physical impacts to airspace, it is important to note that the FAA has a rigorous process, which involves several lines-of-business with technical expertise for considering potential hazards. Table 2.1 provides a listing of FAA divisions and their corresponding evaluation responsibilities.

2.6 Aviation Safety Evaluation of Energy Technologies

ACRP Synthesis 28 presented a synthesis of airport practice regarding energy technologies and airports.[33] It summarized five types of energy facilities that could affect airports and aviation: Solar Photovoltaic, Concentrating Solar Power, Wind Farms, Traditional Power Plants, and Electrical Transmission. It also identified six types of potential impacts on airspace and airports from energy technologies. This is the starting point for research and guidance undertaken as part of this project.

1. **Physical Penetration of Airspace:** All energy technologies (and other structures for that matter) have the potential to penetrate airspace depending on proximity to airports. However, any structure rising more than 200 ft. above existing ground elevation penetrates airspace. Utility-scale wind turbines currently in design and construction are 400 ft. or taller. Concentrating solar power towers can be over 400 ft. Power plant stacks and parabolic cooling towers are often more than 200 ft. For other structures under 200 ft. (e.g., drill rig or transmission tower), a physical penetration will occur when located in relatively close proximity to an airport. At least these potential impacts are well quantified.
2. **Radar Interference:** Because radar interference is most often caused by a physical barrier between a radar and a receptor (i.e., plane or airport) sending or receiving a radar signal, most energy technologies can produce an impact if sited too close to a radar installation. However, the greatest problem has been the construction of thousands of 400-foot-tall wind turbines that have been located in radar communication corridors. The wind farms create radar shadows

[33]Barrett, S. and P. DeVita, *ACRP Synthesis 28: Investigating Safety Impacts of Energy Technologies on Airports and Aviation*, Transportation Research Board of the National Academies, Washington, DC, 2011.

behind which the radar signal cannot reach, producing a "blind spot." The rotation of the wind farm blades also creates a signal received by radars that produces clutter, degrading the effectiveness of the radar.

3. **Visual Impact from Glare:** Glare is produced when light from a source or reflected from a surface impairs a receptor's view. Impacts of glare in the energy sector have been primarily associated with solar power facilities including photovoltaic (PV) panels and concentrated solar power (CSP) systems. Glare impacts from CSP systems are expected, as they use mirrors at centralized power plants, but glare impacts from PV installations may be unexpected, as they produce electricity by absorbing (rather than reflecting) sunlight. However, solar PV is being located on airport property to provide cost savings and produce alternative revenue and their close proximity to sensitive airport receptors such as the air traffic controllers and pilots on final approach is producing potential glare effects.
4. **Thermal Plume Turbulence:** There are two primary sources of thermal plume turbulence from traditional steam generation power plants: (1) heated exhaust from a stack and (2) waste heat from cooling towers. Power plants fired by combustion fuels (e.g., coal, oil, natural gas, and biomass) produce a heated exhaust that is released from a stack. In addition, all steam power plants, whether powered by combustible fuels or concentrating solar power, produce waste heat that must be released into the atmosphere more often through dry cooling (e.g., an Air-Cooled Condenser). In each of these cases, hot, rising, invisible air is released, and poses a potential destabilizing effect on aircraft, particularly smaller ones, flying above these structures. When power plants have been proposed close to airport approach routes, aviation stakeholders have been particularly concerned about impacts of thermal plume turbulence.
5. **Vapor Plume Visual Impact:** Similar to thermal plume turbulence, electricity generation facilities that run a steam turbine with evaporative wet cooling produce a potentially hazardous vapor plume, which can cause a visual impediment.
6. **Wind Turbine Rotor Turbulence:** Wind turbines destabilize the air after it passes by the rotors. In wind farms, the turbines are spaced in part to limit impacts to downstream wind turbines. The destabilized air cannot be seen and can produce a safety hazard to particular aircraft including emergency medical helicopters and agricultural applicators. These issues can be of concern downwind of a single row of wind turbines or on the edge of a wind farm.

As an introduction to Chapter 3, Table 2.2 provides a summary of findings from research for this Guidebook, organized according to energy technology type and including the aviation infrastructure that could be affected, potential impact types, and possible mitigation countermeasures.

Table 2.3 defines the major safety impacts of various energy technologies and provides regulatory or literature resources for citation and further review.

Table 2.2. Potential impacts of energy technologies on aviation and related mitigation options.

Energy Technology	Infrastructure Affected	Potential Impacts	Mitigation Options
Wind Farms	Primary radar, Secondary Surveillance Radar (SSR), Avionics, Doppler voice messages, Navigation aids, Physical hazard for aircraft	1. Error on radars due to clutter interference, Doppler shift or spread reflection, refraction and diffraction 2. Shadowing or masking effect if turbine is between radar and a target 3. Collision with structure including Meteorological Evaluations Towers (METs)	1. Design modification in wind turbines. 2. Reduction of telemetry from turbines to radar and reduce radar signature 3. Upgrading radar system 4. Adding gap fillers, Moving Target Indicator (MTI), Moving Target Detection (MTD) filters to remove echoes and unnecessary clutter 5. Lighting and marking including METs
Solar Photovoltaic Cells (PV)	Human receptors specifically air traffic controllers and pilots	1. Glare can visually impair airport sensitive receptors, producing a hazardous safety condition	1. Appropriate siting of PV plants relative to airports 2. Use of PV modules that mitigate glare
Concentrated Solar Power (CSP)	Radars, Visual issues for pilot and air traffic controller, Physical hazard for aircraft	1. Glare from mirrors or receivers can impair human receptors or optical sensors 2. Thermal emissions from receivers may interfere with infrared sensors 3. Thermal plumes from receiver or cooling towers may impact small aircraft	1. Appropriate siting of CSP plants relative to airports
Drill Rigs	Physical hazard for aircraft, Visibility issues for pilot and air traffic controller	1. Flares from drill rigs can cause reduced visibility 2. National Environmental Policy Act (NEPA) issue of wildlife hazards due to ponds for drill rigs	1. Appropriate siting 2. Prohibitions on flares 3. Filling ponds after constructions

(continued on next page)

Table 2.2. (Continued).

Energy Technology	Infrastructure Affected	Potential Impacts	Mitigation Options
Electrical Transmission Lines	Physical hazard for aircraft, Radars, other navigation aids	1. Unnoticed/unmarked structures becoming a hazard to air navigation 2. Communication system interference due to electromagnetic release for line above 345kv	1. Siting guidelines and avoiding locations which interfere with the airspace
Power Plant Stack	Destabilizing conditions for pilots	1. Thermal plumes, which can cause air turbulence leading to communications interference and visual impacts 2. Vapor plumes, which can reduce the visibility for pilots and air traffic controllers	1. Modifications in siting and height of power plant towers 2. Modifying the aircraft procedures to avoid the thermal plumes and vapor plumes effects
Cooling Tower	Destabilizing conditions for pilots	1. Thermal plumes and vapor plumes	1. Modifications in siting and height of towers

Table 2.3. Regulation and research—safety impacts of energy technologies.

Safety Impacts	Definition	Regulation/Documents
Physical Penetration of Airspace	The height of energy facilities leads to visibility issues for pilots and controllers. The structure impedes by being in the line of sight of air traffic control.	a. FAA Order JO 7400.2J, "Procedures for Handling Airspace Matters"[1] b. 14 CFR Part 77[2] c. ACRP Report 38: "Understanding Airspace, Objects, and Their Effects on Airports"[3]
Communications Interference	The physical height or the frequency bands of the different energy facilities interfere with the communication aids of air traffic control. The other factor that interferes with the communications is the electromagnetic interference.	a. FAA, "Technical Guidance for Evaluating Selected Solar Technologies at Airports"[4] b. U.S. Transportation Command, "Assessment of Wind Farm Construction on Radar Performance, Cooperative Research and Development Agreement, Research Conclusions and Recommendations"[5] c. ACRP Synthesis Report 28, "Investigating Safety Impacts of Energy Technologies on Airports and Aviation"[6] d. FAA Order 6310.6, "Primary/Secondary Terminal Radar Siting Handbook"[7] e. FAA Order 6340.15, "Primary/Secondary En Route Radar Siting Handbook"[8] f. FAA Order 6820.10, "VOR, VOR/DME and VORTAC Siting Criteria"[9] g. NTIA, "Assessment of the Effects of Wind Turbines on Air Traffic Control Radars"[10]
Other Visual Impacts	The other visual impacts are due to thermal plume, vapor plume turbulence, and glare and glint from reflective surfaces of the energy facilities.	a. FAA, "Technical Guidance for Evaluating Selected Solar Technologies at Airports"[4] b. FAA, "Safety Risk Analysis of Aircraft Overflight of Industrial Exhaust Plumes" [11] c. FAA, "Aeronautical Information Manual," Section 5, Potential Flight Hazards.[12]
Rotor Turbulence	The turbulence of rotors of wind turbines causes cluttering and several other issues that leads to radars detecting moving objects (aircraft) incorrectly.	a. JASON, "Wind Farms and Radar "[13] b. ACRP Synthesis Report 28 Investigating Safety Impacts of Energy Technologies on Airports and Aviation[6]

Sources:

1. FAA, Order JO 7400.2J, "Procedures for Handling Airspace Matters," February 9, 2012.
2. 14 CFR Part 77
3. Leigh Fisher Associates, "ACRP Report 38: Understanding Airspace, Objects and Their Effects on Airports," Washington, DC.
4. FAA, "Technical Guidance for Evaluating Selected Solar Technologies at Airports," November 2010.
5. U.S. Transportation Command (TRANSCOM), "Assessment of Wind Farm Construction on Radar Performance, Cooperative Research and Development Agreement, Research Conclusions and Recommendations," 2010.
6. Barrett, S., and P. DeVita, "Synthesis 28: Investigating Safety Impacts of Energy Technologies on Airports and Aviation," Airport Cooperative Research Program, Transportation Research Board, Washington, DC, 2011.FAA, Order 6310, *Primary/Secondary Terminal Radar Siting Handbook*, 1976.
7. FAA Order 6310.6, "Primary/Secondary Terminal Radar Siting Handbook," 1976
8. FAA, Order 6340.15, "Primary/Secondary En Route Radar Siting Handbook," 1983.
9. FAA, Order 6820.10, "VOR, VOR/DME, and VORTAC Siting Criteria," 1986.
10. Lemmon, J., et al., "Assessment of the Effects of Wind Turbines on Air Traffic Control Radars," National Telecommunications & Information Administration, Technical Report TR-08-454, 2008.
11. FAA, "Safety Risk Analysis of Aircraft Overflight of Industrial Exhaust Plumes," DOT-FAA-AFS-420-6-1, 2006.
12. FAA, "Aeronautical Information Manual: Official Guide to Basic Flight Information and ATC Procedures," August 22, 2013: http://www.faa.gov/air_traffic/publications/atpubs/aim/index.htm.
13. Brenner, M. et al. "Wind Farms and Radar," JASON, MITRE Corporation, JSR-08-125, January 2008.

What do accident reports tell us about Energy Facilities' Compatibility with Airports and Airspace?

The premise of this research is that energy technologies may pose an air safety hazard, so it is logical to look at accident reports to see if there is any documented supporting evidence.

Research for this Guidebook included a review of National Transportation Safety Board (NTSB) aircraft accident database records between January 1, 2001, and June 23, 2013, for key words related to wind turbines and meteorological evaluation towers (METs) used to measure wind. The search resulted in 1,498 individual records key word matches, containing the following list of aircraft accidents and their likely contributing causes:

Accident Report Number	Noted Cause State
WPR11LA094	MET Collision (CA)
DFW05LA126	MET Collision (TX)
SEA04LA027	MET Collision (OR)
WPR11LA375*	80 ft. Unmarked Tower (AZ)
CEN11CA545	Collision with a Windmill Blade (IA)
CHI04LA225	Collision with a 25' Windmill (ND)
LCHI08LA080	Possible Rotor Wake Turbulence (MN)
AX01FA253	Possible Rotor Wake Turbulence (CA)

* In reviewing the text in this report, a clear determination could not be made on the type of tower.

A separate research effort involved a review of the Aviation Safety Reporting System (ASRS) for a variety of keywords related to energy technologies, indicating 17 safety events, related mainly to power plants. The primary causes for these events included airspace violation (i.e., physical obstruction encountered by unaware pilots) and critical aircraft equipment problems. However, that search included no events related to solar energy or other technologies.

To obtain more information related to other causes for safety events, researchers then performed a modified search that examined types of impacts that might result from energy projects (e.g., glare or turbulence that could be caused by energy facilities), indicating 106 incidents from 2007 to 2012 for which glare was a noted cause of a safety event. Search results included day and night reports demonstrating the difficulty in equating "glare" impacts to those produced by an energy technology (e.g., solar PV). See Appendix C for additional information on accident report data.

CHAPTER 3

Energy Technologies and Aviation Safety Impacts

This chapter provides a review of research and industry trends related to the following energy technologies, which present certain aviation safety challenges: solar, wind, oil and gas drilling, conventional power plants, and electricity transmission.

Each section pertains to a particular technology type, beginning with the context for examining aviation safety issues for each technology, along with the research objectives for this project. After this introductory section, an overview of the technology is presented, followed by potential aviation impacts, methods to assess and manage impact, applicable experiences with these technologies in the aviation environment, and lessons learned that inform guidelines and best practices. Finally, in-depth case studies of specific energy projects at or near airports are used to demonstrate relevant issues and potential solutions.

3.1 Solar Power

3.1.1 Research Context

The deployment of solar power has expanded throughout the United States over the past 5 years. Annual solar installations have increased tenfold since 2008, from about 300 MW to over 3,000 MW in 2012. Decreasing costs of solar electricity have driven this growth, as indicated by a 60% reduction in the cost of solar panels over the past 2 years. In addition to lower solar costs, a variety of incentives are also creating a burgeoning solar market, including tax credits, purchasing mandates by federal agencies, and state-level renewable energy portfolio standards (RPS). The amount of electricity produced by solar in the United States is now enough to power 1.3 million homes.[34]

Moreover, lower installation costs have led to an increasing number of solar projects at airports. The partnership between airports and solar energy is a logical one given their open landscapes, the availability of large surfaces on buildings and open land to site projects, and the proximity to high-load electricity transmission infrastructure that airports provide. Airport managers have also recognized the business advantages of solar power as a source of alternative revenue and long-term cost savings. In addition, public policy benefits to the state, county, and municipal government agencies that manage public airports offer a purposeful basis for these projects, including the opportunity to achieve goals related to greenhouse gas reduction.

This increased use of solar energy in and around airports is juxtaposed with the prudent functionality of airports and the primary mission of the FAA to ensure safe and efficient air travel. While early projects demonstrated a strong level of compatibility, recent observations of glare from solar projects have ushered in an increased level of scrutiny and concern. The central question for the FAA when ruling on a proposed solar project is "Will it pose a glare impact?"

3.1.2 What Is Glare?

The U.S. Department of Transportation (DOT), FAA, U.S. Air Force (USAF), National Highway Traffic Safety Administration (NHTSA), and other agencies have raised concerns

CRITICAL RESEARCH NEED—Solar Power

Conduct directed studies to increase the knowledge base about the potential impacts of glare on airport sensitive receptors and use this new information to improve siting and assessment.

[34]Solar Energy Industry Association, "Solar Energy Facts: Q1 2013," 2013: http://www.seia.org/sites/default/files/Q1%202013%20SMI%20Fact%20Sheetv3.pdf.

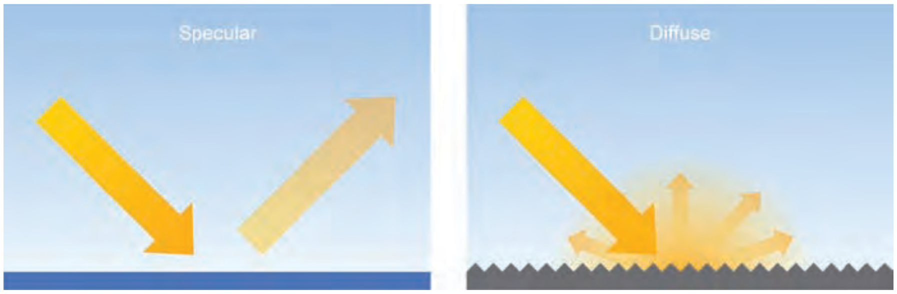


Figure 3.1. Comparison of reflections—smooth and rough surfaces.

over glare from solar energy installations and its impact on pilots, air traffic controllers, and motorists. Glare from direct sunlight has been recognized for many years as a potential hazard for motorists and pilots.[35,36,37] Reports citing NHTSA data estimate that solar glare causes nearly 200 fatalities and thousands of accidents involving motor vehicles each year.[38] The FAA has reported that glare from direct sunlight contributed to nearly a dozen aviation accidents on average each year during an 11-year study.[39]

Glare occurs when sunlight causes a temporary visual impairment to an observer. Glare can be produced when looking directly at the sun, including while driving in the direction of the sun after sunrise or sunset, or at any time of day when sunlight is returned to the observer from a reflective surface. Surfaces that produce glare include mirrors, metal roofs, glass, and motionless bodies of water. Smooth, polished surfaces (e.g., glass) cause a specular reflection that is more direct and intense than reflections from rough surfaces, which become diffuse and are less impactful (see Figure 3.1). Although solar photovoltaic (PV) technology is designed to be absorptive of sunlight, it can still produce glare due to its glass surface. Solar power projects with a high concentration of mirrors pose a greater propensity to produce glare and potential for specular reflection, causing the concern that glare could cause a momentary visual impairment to air traffic controllers or pilots depending on the location of the solar project.

While most problems related to glare from direct sunlight are predictable, occurring during the mornings and evenings when the sun is close to the horizon (see Figure 3.2), solar glare caused by reflections from solar energy installations can occur at varying times in unexpected locations. Glint (i.e., a momentary flash of light) and glare (i.e., a more continuous source of excessive brightness relative to the ambient lighting) can occur from various solar energy components, such as PV modules, concentrating solar collectors/mirrors, and receivers (Figure 3.3). Impacts of glint and glare on eyesight can include discomfort, disability, veiling effects, after-image effects, and retinal burn.[40,41,42,43,44,45,46] Glare affecting aviation receptors can result in after-image effects and veiling (e.g., solar glare on a windshield that might mask pedestrians or vehicles).

Figure 3.2. Highway road sign alerting drivers of potential solar glare.

[35]Saur, R., and S. Dobrash, "Duration of Afterimage Disability after Viewing Simulated Sun Reflections," *Applied Optics*, Vol. 8, pp. 1799–1801, 1969.
[36]ABC News, 20/20, "Sun Glare—Sight Unseen," 1999.
[37]Nakagawara, V., K. Wood, and R. Montgomery, "Natural Sunlight and Its Association to Aviation Accidents: Frequency and Prevention," Federal Aviation Administration, Civil Aerospace Medical Institute DOT/FAA/AM-03/6, 2003.
[38]Costantinou, M., "Glaring Danger—Bright Sun, Deadly Collisions," *San Francisco Examiner*, October 12, 1998.
[39]Ibid.

[40]Saur and Dobrash, 1969.
[41]Aslam, T., D. Haider, and I. Murray, "Principles of disability glare measurement: an ophthalmological perspective," *Acta Ophthalmologica Scandinavica*, Vol. 85, pp. 354–360, 2007.
[42]Babizhayev, M., 2003, "Glare disability and driving safety," *Ophthalmic Research*, Vol. 35, pp. 19–25.
[43]Bhise, V., and S. Sethumadhavan, "Effect of Windshield Veiling Glare on Driver Visibility," *Transportation Research Record: Journal of the Transportation Research Board No. 2056*, pp. 1–8, 2008.
[44]Ho, C., C. Ghanbari, and R. Diver, "Methodology to Assess Potential Glint and Glare Hazards From Concentrating Solar Power Plants: Analytical Models and Experimental Validation," *Journal of Solar Energy Engineering—Transactions of the ASME*, Vol. 133, 2011.
[45]Osterhaus, W., "Discomfort glare assessment and prevention for daylight applications in office environments," *Solar Energy*, Vol. 79, pp. 140–158, 2005.
[46]Sliney, D., and B. Freasier, "Evaluation of Optical Radiation Hazards," *Applied Optics*, Vol. 12, pp. 1–24, 1973.

Figure 3.3. Example of glare viewed from a solar PV facility.

To mitigate these risks, various federal, state, and municipal government codes and regulations seek to prevent harmful glare from solar energy installations.[47] Additionally, the FAA recently announced that it would disallow any new solar installations near airports without a quantitative glare analysis, including an assessment of visual impacts.

3.1.3 How Is Glare Characterized?

The first significant solar projects at airports began in the early 2000s. The FAA's approval of the first projects on airport property included questions about glare. These were typically addressed through a qualitative description of solar PV's absorptive purpose with an occasional field test coordinating with the tower controllers to see what panel reflection might look like.

With a first phase of projects built and operational and a growing number of proposals for new projects, the FAA developed "Technical Guidance for Selected Solar Technologies at Airports," also referred to as "the Solar Guide," released in November 2010. The Solar Guide was intended to be a central reference for solar PV projects at airports to be used by FAA project reviewers, airports, and industry. It provided relevant information on solar and airports including airspace evaluation issues such as glare. It stated that all solar projects on airport property should submit a Form 7460, "Notice of Proposed Construction or Alteration," due to potential glare. That chapter also offered options for providing FAA with information on potential glare based on the specific circumstances of the project. These data options were based on methods employed from past projects and included qualitative information, field-testing with a solar panel, and quantitative information generated through computer modeling.

In May 2012, a project installed on top of a parking garage at Manchester-Boston Regional Airport generated glare impacts on the air traffic control tower (ATCT), constituting the first reported observation of such glare impacts. In response, the FAA began requiring quantitative modeling for all new solar projects proposed on airport property. In addition, the FAA began working with the Department of Energy (DOE) Sandia National Laboratories to develop a single modeling tool in order to provide high-accuracy predictions of potential impacts on airport sensitive receptors and allow for evaluation of design alternatives to avoid glare impacts. Section 3.1.4 provides details regarding the model developed by Sandia, called the Solar Glare Hazard Analysis Tool (SGHAT).

In September 2012, the FAA issued a memorandum entitled "Interim Guidance on Land Uses in the Runway Protection Zone (RPZ)" to provide enhanced clarity on FAA policy. A comprehensive update to the "Airport Design" Advisory Circular (AC 150/5300-13A) was released in September 2012, including a statement that "it is desirable to clear all objects from the RPZ." It also states that some land uses are conditionally permitted while others are prohibited and that the function of the RPZ is to enhance the protection of people and property on the ground. This is best achieved through airport owner control over RPZs, preferably exercised through the acquisition of sufficient property interest in the RPZ and maintaining clearance of RPZ areas from incompatible objects and activities. While the "Object Free Area" specifically prohibits any structures except for frangible items associated with air navigation, the RPZ does not prohibit many land uses but discourages them based on proximity to a potential aircraft mishap.

The "Interim Guidance on Land Uses in the RPZ" memo states that certain new or modified land uses in the RPZ require coordination with the FAA APP-400. Included in the list of land uses requiring coordination with APP-400 is "above-ground utility infrastructure (i.e., electrical substations), including any type of solar panel installations." Prior to coordination with APP-400, ATO Regional Offices and Airport District Offices (ADOs) are directed to work with airport sponsors to identify and document a full range of alternatives that could avoid introducing the land use to the RPZ, minimize the impact of the land use in the RPZ, and mitigate the potential risk to people and property on the ground. The two primary issues associated with siting solar projects in RPZs are (1) the risk to property for the solar facility owner and (2) the risk to aircraft from solar glare.

3.1.4 How Is Glare Managed?

Sandia National Laboratories has developed a web-based interactive Solar Glare Hazard Analysis Tool (SGHAT),

[47] U.S. Department of Energy (DOE), Office of Energy Efficiency & Renewable Energy (EERE), "SunShot Initiative—Examples of Codes that Address Glare from Solar Energy Systems," 2012: http://www4.eere.energy.gov/solar/sunshot/resource_center/ask/question/question_11.

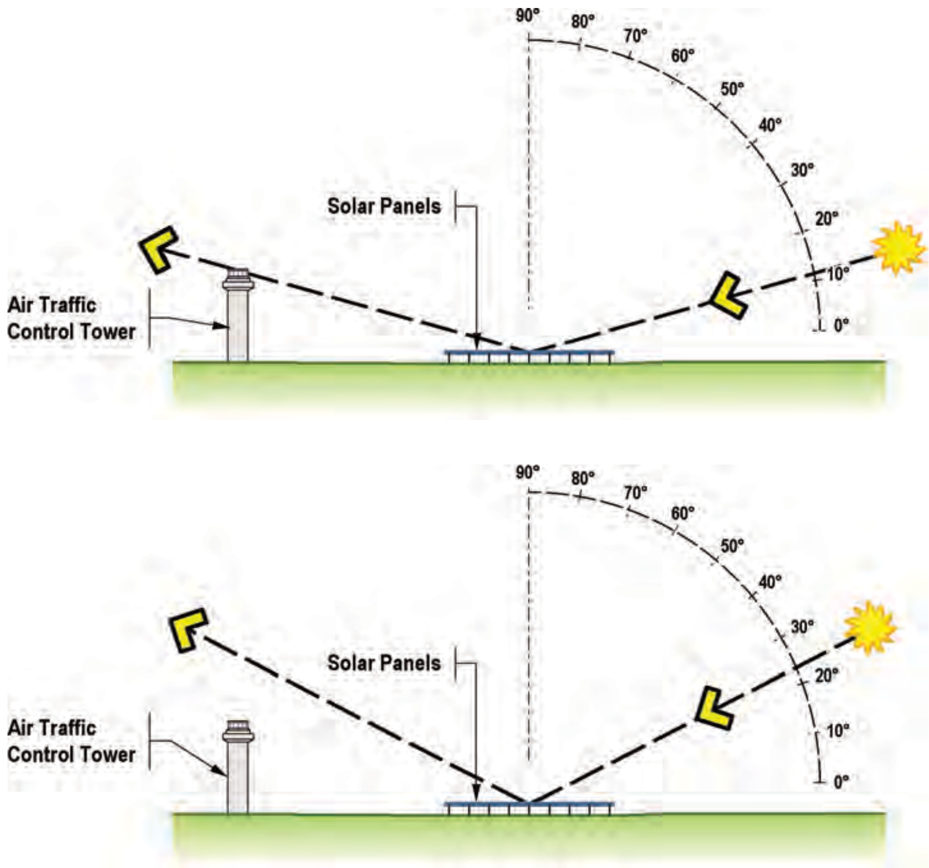


Figure 3.4. Reflection impacts as the sun rises.

which provides a quantified assessment of the following information:[48]

- Time and place that glare will occur throughout the year for a prescribed solar installation
- Potential effects on the human eye at locations where glare occurs
- Estimate of the maximum annual energy produced by the solar energy system

The SGHAT employs an interactive Google map where the user can quickly locate a site, draw an outline of the proposed PV array, and specify observer locations or paths. It automatically records latitude, longitude, and elevation through the Google interface, providing necessary information for sun position and vector calculations. The user also enters additional information regarding the orientation and tilt of the PV panels, reflectance, environment, and ocular factors. SGHAT then employs cone optics to account for beam spreading by integrating both the sun shape and scattering from optical surface errors to produce a cone of reflected sunlight. Rather than using millions of randomly emitted rays employed by ray-tracing methods, it uses a single ray based on the position of the sun at each time-step and orientation of the prescribed array to determine the reflected cone vector and whether glare is visible at prescribed observer locations. If glare is found, the tool calculates the retinal irradiance and subtended angle (or size) of the glare source to predict potential ocular hazards, ranging from temporary after-image effects to retinal burn. The results are presented in a simple, easy-to-interpret plot that specifies when glare will occur throughout the year, with color codes indicating the potential ocular hazard. The tool can also predict relative energy production while evaluating alternative designs, layouts, and locations to identify configurations that maximize energy production while mitigating the impacts of glare. Thus, it also serves as a design optimization tool.

The FAA is requiring the use of SGHAT to evaluate potential impacts of glare on airport sensitive receptors, which have been identified by ATCT operators and pilots on final approach to landing. The ATCT is particularly at risk because it is a stationary receptor and its exposure to glare is dependent on the movement of the sun. Figure 3.4 shows a typical example of when an ATCT may be impacted by glare during

[48]Ho, C., and C. Sims, "Solar Glare Hazard Analysis Tool (SGHAT) User's Manual v. 1.0," SAND2012-10761P, Sandia National Laboratories, Albuquerque, NM, 2012: https://share.sandia.gov/phlux.

ACRP Applied Research—Measuring Reflection Values from Solar Panels

One fundamental data source that is currently unavailable is the measurement of reflection from commercially available solar panels. Some manufacturers advertise the availability of anti-reflecting (A/R) coatings. However, there is little information available to quantify the amount of sunlight reflected.

The Sandia National Laboratories conducted solar PV module reflectivity testing as part of this project to improve understanding of the potential for solar panels to produce glare. The total solar reflectivity generally ranged from 6 to 12 percent, while the specular solar reflectivity ranged from approximately 1 to 4 percent. Interestingly, the deep-textured glass sample did not show any measurable specular reflectance, which indicates a significant amount of scattering of the reflected light relative to smooth or lightly textured surfaces. Smooth surfaces, such as mirrors and smooth glass, produce more specular reflections with greater intensity and tighter beams (i.e., larger retinal irradiances and smaller subtended angles), while solar receivers, textured glass, and anti-reflective coatings produce more diffuse reflections with lower solar intensities but greater subtended angles (see Figure 3.5). However, it is important to note that these values are for an incidence angle of 20 degrees. At higher incidence angles, the reflectivity can increase significantly. While these data are not yet ready to be directly applied to the Guidance, it does suggest that use of the deep-textured panels at airports may be a siting option. Reflectivity data is included in Appendix D.

Left: smooth float glass; Middle: glass with anti-reflective coating;
Right: deeply textured glass
Photo credit: Cliff Ho, Sandia National Laboratories; PV samples from Canadian Solar, Inc.

Figure 3.5. PV glass samples resulting in different solar glare intensity and size.

Developing New Data—Survey of Pilot Experience with Solar Glare

Research for this Guidebook included a flight crew survey designed and distributed to obtain empirical information from pilots on the sources of their experience with solar glare in general and solar power facilities specifically. Commercial airline and general aviation pilots completed the survey online from October 2012 through July 2013, with 383 total pilots responding. See Appendix E.

Thirty-two (32) percent of the respondents operate primarily at airports with known solar energy facilities. Of the pilots who stated that they have experienced solar glare, they noted the following potential sources:

1. Sun at sunrise or sunset—83 percent
2. Bodies of water—57 percent
3. Glass buildings—37 percent
4. Windows—26 percent
5. Building roofs—17 percent

When asked how they normally deal with glare, most pilots stated that they adjust shading in the cockpit (83 percent) and use sunglasses (75 percent). Many pilots noted that they attempt to alter their direction of view (48 percent), while others said they wear baseball-style hats, adjust their seat height, or simply use their hands to block the glare.

As shown in Figure 3.6, 45 percent of respondents stated that they were aware of solar power facilities at airports at which they operate. While 44 percent were uncertain of the type of technology observed, 31 percent said they observed concentrating solar power (CSP) and 25 percent observed solar photovoltaic (PV) technology. Nine percent of respondents

Developing New Data—Survey of Pilot Experience with Solar Glare *(Continued)*

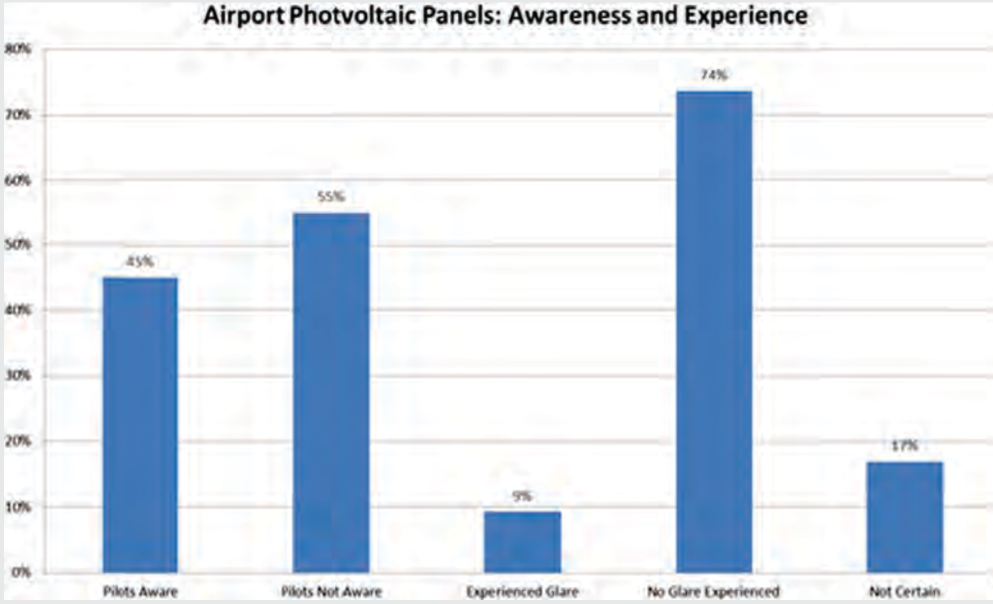


Figure 3.6. Airport photovoltaic panels: awareness and experience.

who were aware of solar projects indicated that they had experienced glare while 74 percent did not. Of the pilots who did experience glare, 4 percent classified the glare as a "significant nuisance," 24 percent as a "moderate nuisance," and 72 percent as "not a nuisance."

When asked whether they consider solar glare to be a safety concern for pilots, 12 percent said "yes," 45 percent said "no," 27 percent were "uncertain," and 15 percent did not respond. Finally, when asked if they had reported a glare problem to authorities, 1 percent responded "yes," 75 percent said "no," 5 percent noted some "other" related action, and 18 percent did not respond. These data provide immediate value to practioners in assessing the potential impacts of solar PV projects on pilots.

sunrise and how the glare diminishes as the sun rises in the sky. Pilot impacts are more limited because their aircraft is moving and will pass through a glare exposure zone typically in seconds (or tens of seconds) and pilots are also exposed to many sources of glare when in flight and manage the glare with sunglasses, cockpit shades, and other methods.

3.1.5 Case Study: Manchester-Boston Regional Airport

In 2012, PV panels at airports received increased attention when glare from a newly installed PV array on a parking garage at Manchester-Boston Regional Airport (MHT) had to be covered with a tarp because it caused nuisance glare to air traffic controllers in the nearby control tower (see Figure 3.7).[49] After the PV array was installed, Sandia used SGHAT and worked with the FAA and the airport to determine alternative configurations that would mitigate glare to the control tower and approaching flight paths. The team used SGHAT (see Figure 3.8) to evaluate dozens of alternative configurations (e.g., tilt, orientation) and was able to determine a configuration that would mitigate glare while maintaining the desired energy production.

Figure 3.9 shows the results of the SGHAT glare analysis for MHT. The dots in the plot represent occurrences of glare

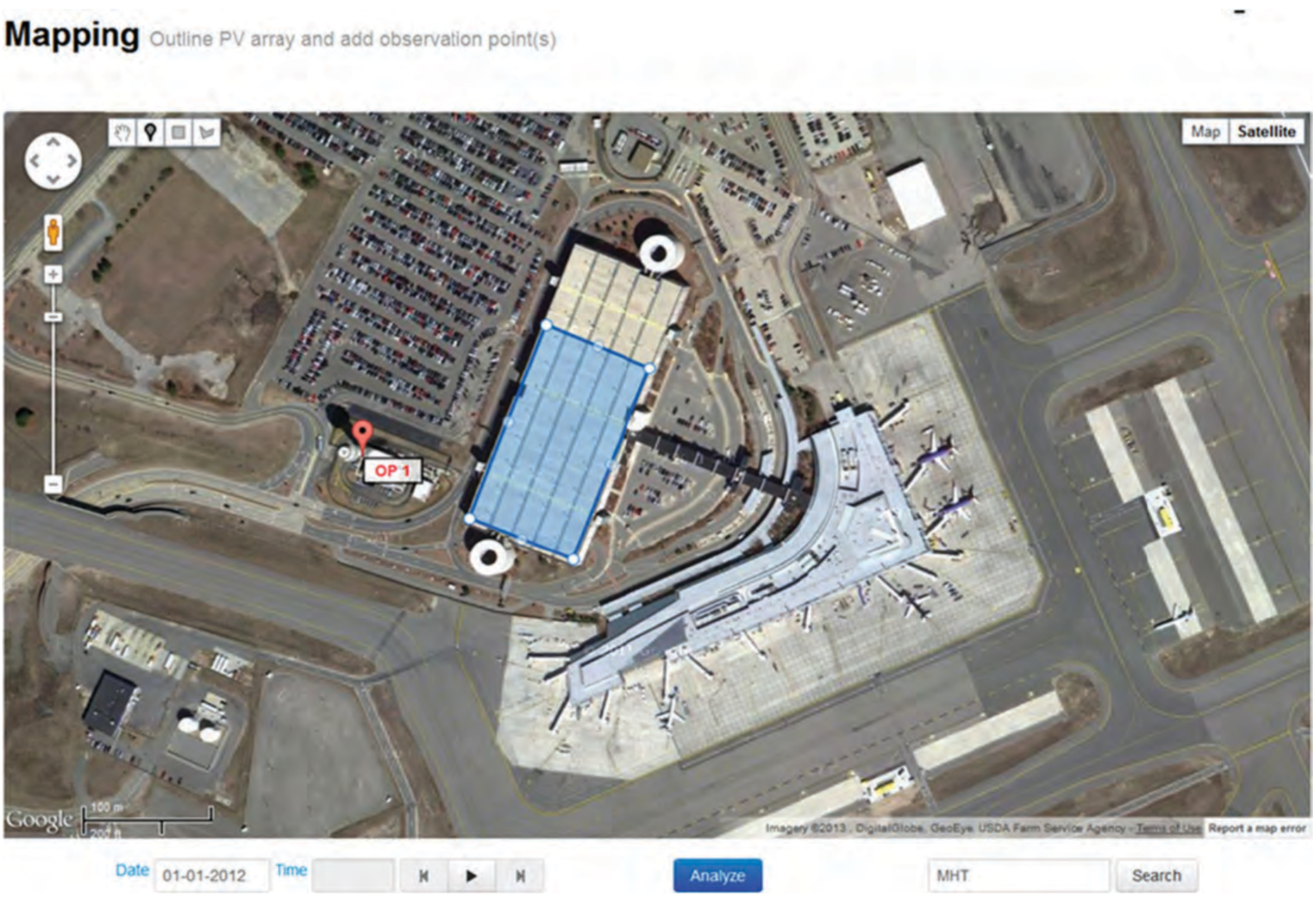
[49] CNN, "Solar panels cause trouble at airport," August 31, 2012: http://www.cnn.com/video/standard.html?hpt=hp_t3#/video/bestoftv/2012/09/01/nh-dnt-airport-solar-panels-safety-issues.cnn.

Date/Time: 7:15AM EST, April 27, 2012

Figure 3.7. Glare viewed from MHT air traffic control tower.

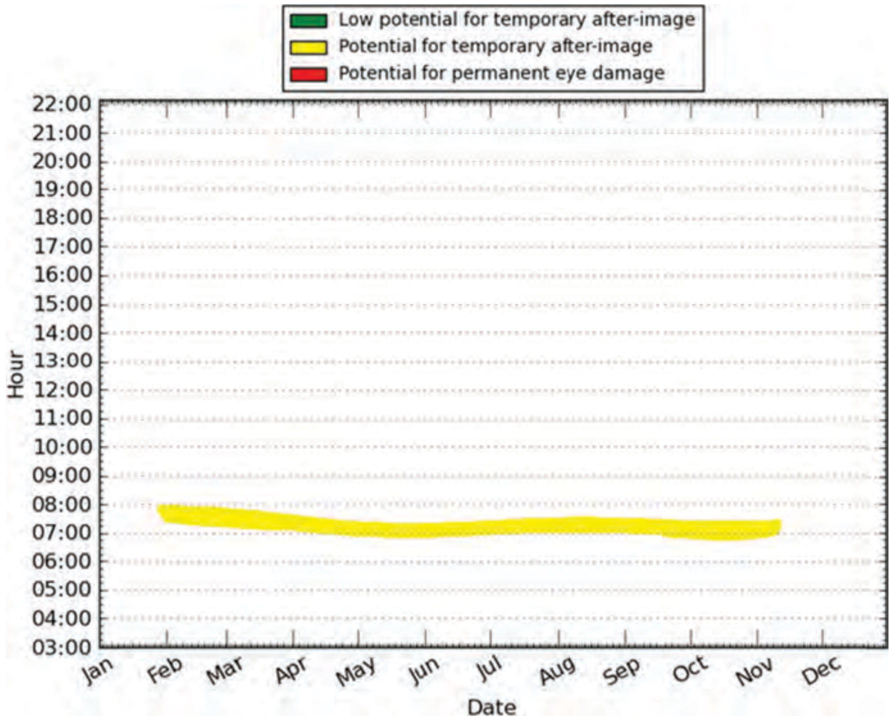
as viewed from the user-specified observation point relative to the specified PV array as a function of the time of day and day of the year. The color of the dots indicates the potential ocular hazard, which is impacted by the direct normal irradiance (DNI), optical parameters (i.e., reflectance, slope error/scatter), and ocular parameters (pupil diameter, transmission coefficient, ocular focal length). Figure 3.9 indicates that there is a potential for glare that can cause temporary after-image effect (i.e., a lingering image of the glare in the field of view) during the early morning from January through November. The general spatial and temporal pattern of glare on the PV array was identified using SGHAT Glare Animation Feature and is shown in Figure 3.10. These patterns were verified by observations from the control tower.

Photos and videos of glare from the installed PV array at MHT were taken from the ATCT in late April and early May. Figure 3.11 provides a photograph of the glare observed during hours consistent with those predicted by SGHAT. Due to the glare, a tarp was placed over the offend-



Note: PV array (blue outline) and observation point (red marker) entered using drawing tools integrated with Google Maps

Figure 3.8. Screen image of MHT glare analysis.



Note: All times EST (during EDT, add one hour)

Figure 3.9. Glare occurrence and potential for ocular impact in the ATCT.

ing PV modules and had to be moved every few weeks as the sun position changed.

Table 3.1 shows alternative configurations using the same footprint of the PV array that were predicted to produce no glare. The relative annual energy production is also shown for each configuration. In addition, Table 3.1 shows the current PV configuration (200-degree azimuthal angle, 20.6-degree elevation angle) and a maximum energy production configuration (180-degree azimuthal angle, 43-degree elevation angle).

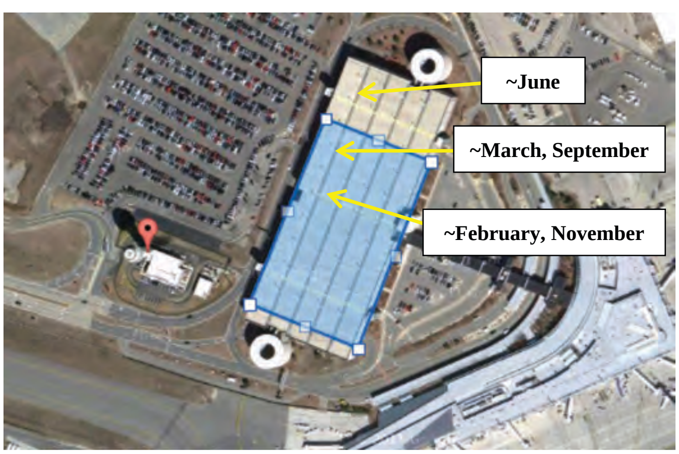
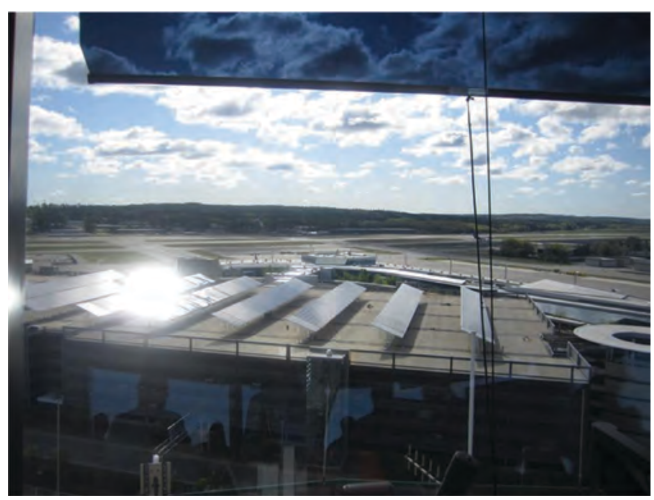


Figure 3.10. Approximate glare locations on PV array throughout year.

Based on a review of the glare analyses, an alternative configuration of the PV modules was recommended, rotating the assemblies 90° counter-clockwise to face east-southeast (110 degrees from due north). The tilt of the modules remains the same. This new configuration was re-evaluated using SGHAT to affirm that glare did not affect the flight patterns approaching the runways.



Note: Photo taken approx. 7:17 AM EST, May 10, 2012; note the tarp placed over some modules

Figure 3.11. Glare viewed from MHT ATCT.

Table 3.1. Alternative no-glare PV array configurations.

Azimuthal Angle (degrees)	Elevation Angle (degrees)	Relative Annual Energy Production
180	43	100.0%[1]
200	20.6	93.9%[2]
120	40	88.9%
120	50	87.2%
110	20.6	82.4%
110	30	85.0%
110	40	84.7%
120	60	83.7%
110	50	82.8%
130	70	81.5%
100	30	80.9%
100	20	80.8%
100	40	79.9%
110	60	79.3%
120	70	78.3%
100	50	77.6%
90	20	77.5%
210	80	76.9%
90	30	76.4%
220	80	75.8%
90	40	74.5%
110	70	74.2%
100	60	74.1%
130	80	74.0%
90	50	71.8%
120	80	71.3%
100	70	69.2%
90	60	68.1%
110	80	67.7%
90	70	63.4%
100	80	63.2%
90	80	57.8%

Notes:
As predicted to produce no glare from perspective of air traffic control tower; azimuthal angle measured clockwise from due north (0°); elevation angle measured from 0° (facing up) to 90° (facing horizontal)

1. Maximum energy production; produces glare to air traffic control tower
2. Current configuration; produces glare to air traffic control tower

3.1.6 Lessons Learned

Understanding of the potential impact of solar glare on airport sensitive receptors has expanded significantly over a short amount of time. When the FAA released the Solar Guide in November 2010, there were very few solar projects at airports and no reports of glare impacts. Glare was assessed primarily in a qualitative fashion and the authors recommended the development of modeling tools to better address the issue. Eighteen months later, the glare incident at MHT focused FAA attention on the potential safety concerns and within 6 months, a modeling tool was developed.[50] Appropriate use of SGHAT and coordination with the FAA will make siting and impact analysis more efficient and accelerate the approval of future solar projects. Additionally, while low-glare glass may not be an explicit project requirement, research for this Guidebook suggests that airports considering solar projects should request feasibility assessments for use of low-glare glass to mitigate glare in Requests for Proposals (i.e., bid solicitation).

3.2 Wind Power

3.2.1 Research Context

Since 2000, wind generation capacity in the United States has increased from 5 GW to 43 GW, and wind could supply 20 percent of the nation's electricity by 2030, equating to

[50] Ho and Sims, 2012.

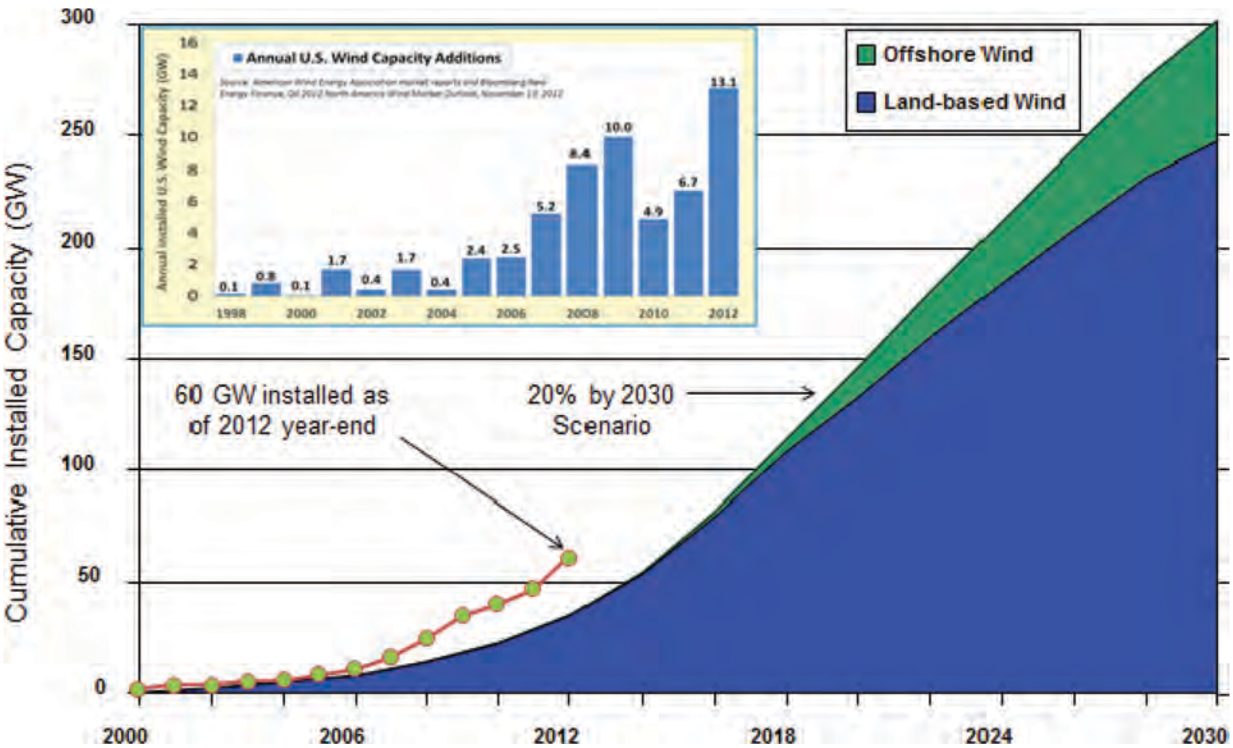


Figure 3.12. Cumulative installed wind power capacity through 2030.[53,54]

300 GW (including 54 GW of offshore wind), as shown in Figure 3.12.[51,52]

A variety of incentives have catalyzed wind power growth, including tax credits, purchasing mandates by federal agencies, and state-level renewable energy portfolio standards (RPS).[55] Examples include the DOE goal of 20 percent by the year 2030,[56] the Department of Defense (DoD) goal of 25 percent by 2025,[57] and the 2004 Colorado initiative whereby Colorado became the first state to pass an RPS. Approximately one-half of all states have followed suit with RPS development, ensuring a growing role for wind energy production.[58]

CRITICAL RESEARCH NEED—Wind Power

Develop a synthesis of aviation safety risk factors related to wind technology to inform siting and operations guidance, including radar interference, wake effects, and MET obstructions.

Wind Turbine Generators (WTGs) have the potential to cause a variety of negative effects on aviation activities. Results from studies done in the United States and Europe have shown that these physical and electromagnetic effects directly affect operational missions conducted by government agencies. Radar systems in particular suffer serious negative effects, although other systems such as communications systems, navigation systems, and even aircraft on runways or approaches are also impacted as well.

3.2.2 What Are the Impacts of Wind Power?

Most contemporary wind turbines are constructed with a three-bladed rotor connected to a generator set atop a

[51]DOE, Office of Energy Efficiency and Renewable Energy (EERE), “20% Wind Energy by 2030, Increasing Wind Energy’s Contribution to U.S. Electricity Supply,” DOE/GO-102008-2567, July 2008: http://www.osti.gov/bridge.

[52]DOE, “A National Offshore Wind Strategy: Creating an Offshore Wind Energy Industry in the United States,” February 2011.

[53]DOE, EERE, “20% Wind Energy by 2030, Increasing Wind Energy’s Contribution to U.S. Electricity Supply,” DOE/GO-102008-2567, July 2008: http://www.osti.gov/bridge.

[54]DOE, “Interagency Field Test & Evaluation, Government Listening Session Overview,” presentation by Jose Zayas, AWEA WindPower 2013 Conference and Exhibition, May 7, 2013.

[55]DOE, EERE, “20% Wind Energy by 2030, Increasing Wind Energy’s Contribution to U.S. Electricity Supply,” DOE/GO-102008-2567, July 2008: http://www.osti.gov/bridge.

[56]Ibid.

[57]DOE, EERE Federal Energy Management Program, “Large-Scale Renewable Energy Guide, Developing Renewable Energy Projects Larger Than 10 MWs at Federal Facilities,” DOE/GO-102013-3915, March 2013: http://www1.eere.energy.gov/femp/.

[58]Wind Energy Association, Monthly Newsletter, March 14, 2013.

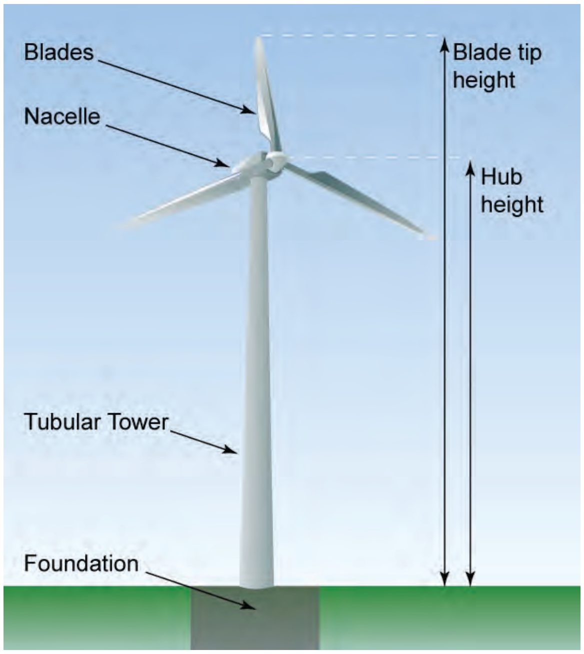


Figure 3.13. Terminology associated with wind turbine generators (WTGs).

monopole tower (see Figure 3.13). The increased capacity over the past 10 years has been primarily achieved by building the towers taller to catch a more consistent wind resource (see Figure 3.14). Current wind turbines have a blade tip height of as much as 500 ft. above ground level (AGL) and heights may continue to increase. Given that defined airspace technically begins at 200 ft. AGL, most wind turbines constructed in the United States have an impact on aviation. Additionally, the NAS consists of more than 23,000 ATC facilities, airports, and NAVAIDs, hundreds of which are located in areas where wind developers would like to build.[59]

The material related to wind power in this Guidebook is intended to address aviation safety issues related to WTGs near airports and ATC facilities. The impacts of wind turbines on airports and airspace include physical penetration, communications systems interference, and rotor blade turbulence, discussed in detail in the following sections. WTG developers should be aware of electromagnetic systems and airspace activities and address the potential project implications early in the planning process, especially those related to FAR Part 77 navigable airspace restrictions.

3.2.2.1 Physical Penetration

Structures that produce a physical penetration to airspace are the simplest to understand. Any structure rising over 200 ft. AGL penetrates the NAS, triggering the requirement for airspace review under FAR Part 77 to determine whether or not the structure creates an airspace hazard. Tall structures located proximate to airports and ATC facilities (e.g., radar) are more likely to produce a potential airspace concern beyond physical impingement. Furthermore, airspace reviews examine individual structures, so cumulative effects of many structures may be more difficult to evaluate. Physical penetration is also an important issue for meteorological test towers, which are deployed to measure wind resources in advance of project development (see Section 3.2.4).

3.2.2.2 Radar

A radar system consists of four major components: (1) a transmitter, (2) a directional antenna, (3) a receiver that processes incoming data, and (4) a display for the operators. The core concept of radar requires the transmission of energy pulses from the antenna in a known direction and a "target" that reflects some amount of that energy (i.e., a "return") back to the antenna where it is received and processed before it is displayed on an operator's panel as a target. The time the energy takes from initial antenna pulse to the time it is received provides the distance or "range" to the target.

The size of the target is determined by the strength of the return, which is a function of the radar cross section (RCS) of the target. Targets with more reflective materials and/or surfaces have a larger RCS. The larger the RCS, the easier it is to distinguish a target from surrounding "clutter." Clutter is everything else the radar sees (e.g., terrain features, birds, bats, insects, weather phenomenon for non-weather radars, and aircraft for weather radars). Radar designers use an array of methods to eliminate clutter so that the target in question stands out. A variety of amplitude threshold techniques provides engineers an array of tools they can use to eliminate clutter (e.g., Plot Amplitude Thresholds [PAT], Range Azimuth Gates [RAG], etc.). Some radars use multiple stacked beams to allow operators to determine an altitude.

In addition to signal strengths, radar designers can use Doppler frequency shift techniques as a way to see and estimate the speed of moving targets, which indicate a "zero" Doppler. This proves useful in eliminating stationary targets (e.g., buildings or terrain) from a radar image. Another way to determine whether a target is moving is to utilize periodic scanning techniques to "take snapshots" of the surveillance area and then compare them to see if a target has moved. This is typically accomplished using rotating antennas or by using phased arrays that focus on smaller areas on a reoccurring basis in order to produce those snapshots. Many other methods exist as well.

[59]FAA, "Instrument Procedures Handbook," FAA-H-8261-1A, 2007.

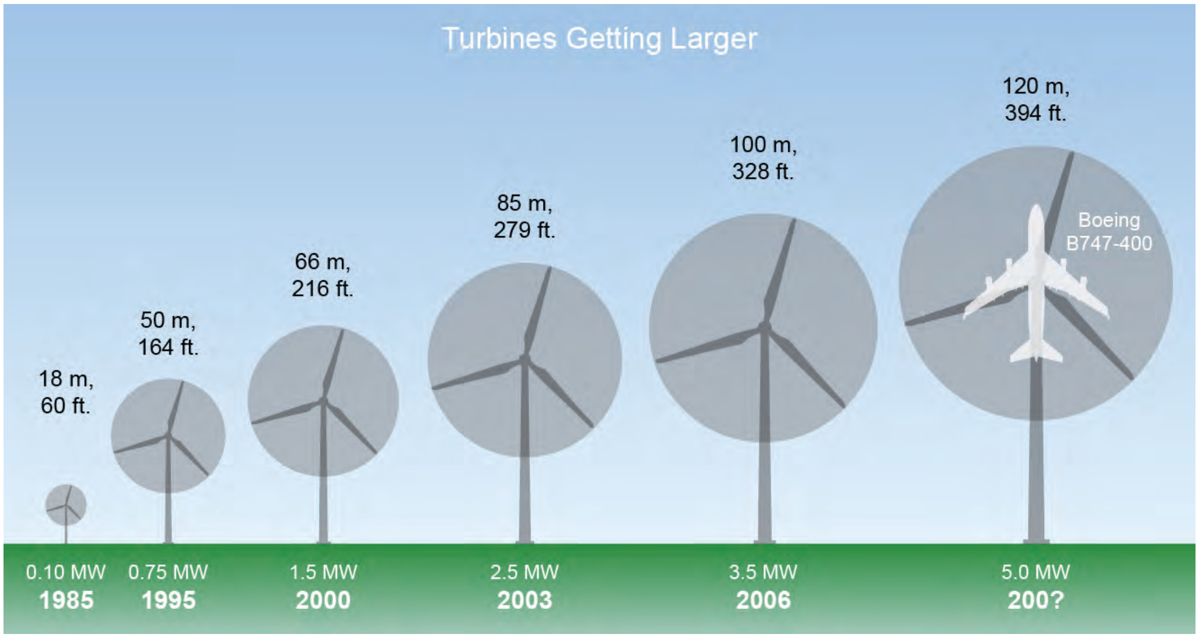


Figure 3.14. Increase in size of WTGs over time.

Radars used for weather employ many of the same general techniques as radars used to detect aircraft. The key difference between them is that the primary objective of weather radar is to measure air density (relating to moisture content) and air mass movements (i.e., winds aloft). These measurements are then translated via weather-based processors to operator displays that meteorologists use to determine weather patterns and provide forecasts.

Examples of affected/suspected radar systems include:

- Long-Range Surveillance Systems (ARSR-1 to 4, CARSR, FPS-117, etc.)
- Terminal Systems (ASR-7, 8, 9, 11, etc.)
- Weather Systems (WSR-88D, TDWR, etc.)
- Marine Systems (CODAR, WERA, etc.)
- Other Key Systems (OTHR, Airborne Systems such as TARS, AWACS, etc.)

WTGs pose particular challenges to radar due to a wide range of variables that include the following: tip speeds over 225 mph (Doppler issue), blade lengths exceeding 50 m long (size), and radar cross sections measuring 30–40 dB relative to 1 square meter (dBsm), also known as clutter.[60] When a developer places tens or hundreds of WTGs in a wind farm, and several wind farms are sited around a single radar site, the capability of that radar may be impacted to the point that the cumulative effects can render the radar ineffective.

As indicated by Figure 3.15, WTGs affect radar systems in a number of ways, reducing their effectiveness to support federal, state, and local activities and missions. The three primary electromagnetic impacts on radars are as follows:[61]

1. Decreased Sensitivity (PD)
2. False Targets (PFA)
3. Corrupted Track Quality

Investigators measure these primary impacts to determine the broader effects on air and weather surveillance missions. In effect, the extent to which particular radar is impacted in these three ways will likely determine whether an objection is raised to any particular wind energy project.

Reviewing agencies and authorities assess the impacts of WTGs on radar differently depending on their core missions. For example, the FAA assesses radar impacts to ensure flight safety, aircraft separation, and other factors related to airspace operations. Other agencies and authorities are listed below with their radar-related concerns:

- **Weather Reporting and Prediction—**Storm and rainfall prediction, tornado warning, etc.
- **Homeland Security—**Border protection, law enforcement, drug interdiction, etc.

[60]DOE, "Interagency Field Test & Evaluation, Government Listening Session Overview," presentation by Jose Zayas, AWEA WindPower 2013 Conference and Exhibition, May 7, 2013.

[61]Ibid.

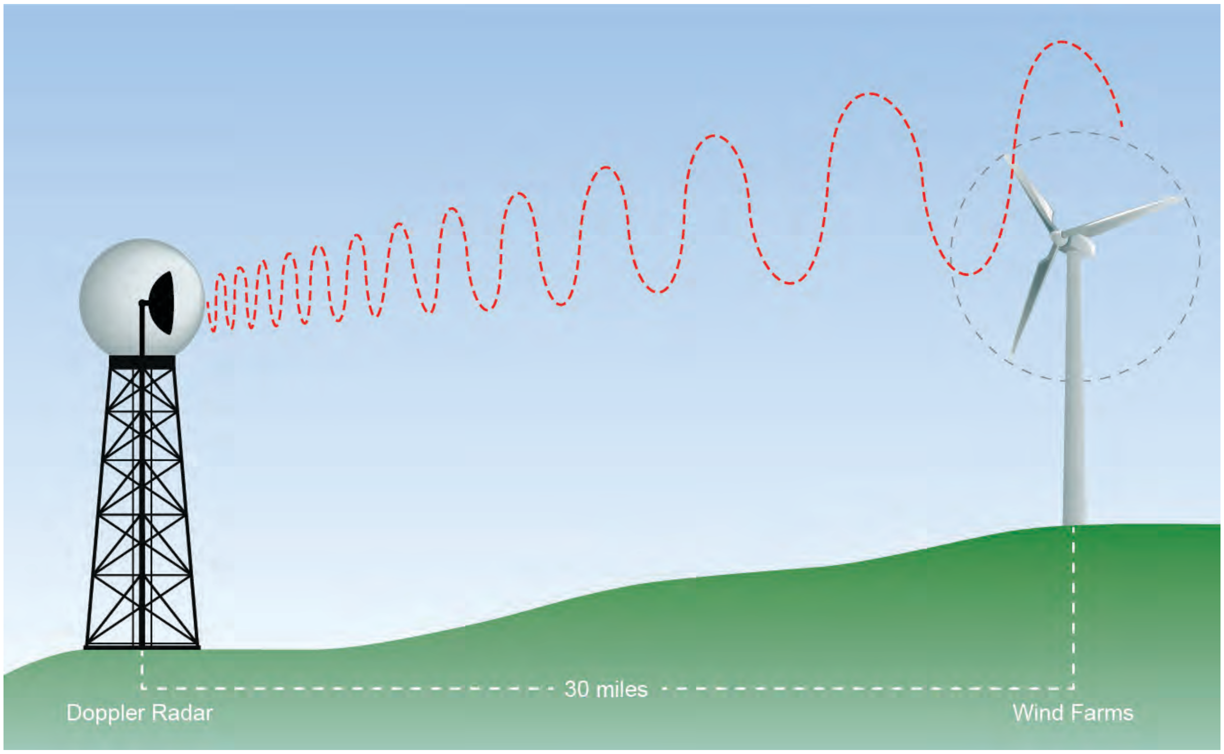


Figure 3.15. WTGs as physical obstructions to radar signals.

- **Homeland Defense**—Aerospace warning/control, air defense, support to law enforcement, etc.
- **Military Training**—Potential for degradation of performance of air traffic control and other radars used during flight training
- **Research, Development, Test and Evaluation**—Developmental and operational testing, and system certification
- **Maritime Patrol**—Coastal navigation, waterway safety, and search and rescue
- **Law Enforcement**—Collateral effects/chain-of-custody for local, state, federal, and tribal agencies
- **Critical Infrastructure Protection**—Nuclear security operations, continuity of government, etc.

3.2.2.3 Rotor Wake Turbulence

ACRP Synthesis 28 provides a description of rotor-induced turbulence: "Wind turbines disrupt uniform air flow causing unseen turbulence produced downstream of wind turbines." Additionally, *ACRP Synthesis 28* points out that, "Turbulence associated with wind turbines is less an issue of predictability, as the turbulence potential can be visualized by the presence of the wind turbines and whether or not they are spinning." The issue is more about understanding the distance that rotor-induced turbulence may occur from a wind turbine and what the degree of turbulence might be compared with other sources of existing natural and fabricated turbulence. Figure 3.16 illustrates the effects of rotor wake turbulence.

Figure 3.16. Fog trailing from Horns Rev offshore wind farm, Denmark.[62]

Based on a review of the issue, concern about turbulence impacts is primarily limited to GA aircraft due to their lightweight airframes and propensity to operate at lower altitudes where turbulence would occur (see Figure 3.17). Aviation

[62]Vattenfall Energy, Christian Steiness, Sweden, 2007.

Figure 3.17. Aerial spray aircraft.

Figure 3.18. Cheetah Rotax from Rainbow Aircraft.[68]

constituents have raised safety concerns about performing services near wind turbines due to potential impacts of turbulence including air ambulance[63] and crop spraying.[63,65,66] There have also been reports from recreational pilots about detecting turbulence downwind from operating wind turbines.

Several studies offer guidance in determining the safest distance for aircraft to travel downwind of a wind turbine:

- **IFT&E Pilot Reports:**[67] During the Interagency Field Test and Evaluation (IFT&E) Program flight campaigns, Cessna 182s were flown as low as 500 ft. above WTGs with little to no effects. When pilots did experience heavy turbulence, their interpretations were that the rising terrain leading up to the turbines exacerbated the turbulence effects and may have been noticeable without the presence of WTGs. In another situation, a light jet aircraft pilot reported he had flown approximately 1,000 ft. behind a wind farm and slightly below rotor tops where the turbines were located on a ridge and experienced turbulence so bad that "he'd never knowingly do it again." Finally, an Ultralight pilot stated he also noted turbulence as he made circuitous flights around wind farms on ridges and he purposefully chose "not to fly on the windier days," partially because he thought that turbulence above was an even bigger concern for his size aircraft.
- **Modeling Impacts on a Cheetah Rotax 582 Ultralight:**[69] A South African study modeled turbulence impacts from utility-scale wind turbines on an Ultralight aircraft (see Figure 3.18) during approach and take-off using computational fluid dynamics (CFD) analysis. It concluded that a minimum safety zone is 5 rotor diameters, though a safety factor should be applied, which would result in a safety zone of 10 to 15 rotor diameters.
- Various Studies have shown that wake effects from a wind farm wake are approximately 20 km independent of the size of the wind farm as well as background meteorology.[70] Measurements at 16 rotor diameters downstream of the wind turbine indicate that turbulence effects are still noticeable.[71] Near-field wake turbulence behind a horizontal axis turbine extends downstream to 3 to 7 blade diameters.[72] Turbine separation in wind farm clusters is 6 to 7 diameters in the direction of the prevailing wind direction and 3 diameters perpendicular to the prevailing conditions. The disruption to wind velocity occurs even at 16 times the blade diameter. This is largely due to the extraction of power from the airstream, and the time it takes the airstream to recover back to the free-airflow. Therefore, it may be necessary to require separation beyond 16 blade diameters.[73]

[63]Multi-Municipal Wind Turbine Working Group, "Letter to the Honourable Deb Mathews, Minister of Health, Toronto, Ontario," sent by elected officials and appointed citizens of Bruce, Grey, Dufferin, Huron, and Perth Counties, Ontario, Canada, May 29, 2012.

[64]Calleja, J., "Wisconsin Applicator Declares Towers Off Limits for Spraying," *Agricultural Aviation*, National Agricultural Aviation Association (NAAA), November/December 2009: http://www.agaviation.org/sites/default/files/ReabeLetter.pdf.

[65]Hunter, A., "Wind Turbines and Aerial Application," *Fly Low, Fly Safe*, Vol. 2, Issue 4, Fall 2011: http://www.nationair.com/pdf/FlyLowFlySafe_Fall10.pdf.

[66]Boorowa District Landscape Guardians, "Wind Turbines and Aviation": http://www.bdlg.org/BDLG%20Brochures/Aviation.pdf. Accessed January 30, 2014.

[67]Interagency Field Test and Evaluation Program (IFT&E), Discussions with Pilots, April 2013.

[68]Cheetah, Photo of Rainbow Aircraft, 2011: http://www.aerotrike.co.za/cheetah/index.html.

[69]Verbeke, J., "The Influence of wind turbine induced turbulence on Ultralight aircraft," KHBO Institute for Fluid Dynamics, Academic Year 2010–2011, Oostende, Belgium.

[70]Baidya Roy, S., "Simulating impacts of wind farms on local hydrometeorology," Aerodyn, 2011.

[71]Vermeer, L. et al., "Wind turbine wake aerodynamics," *Progress in Aerospace Sciences*, Vol. 39, pp. 467–510, 2003.

[72]Holland, R., "Wind turbines Wake Turbulence and Separation": http://www.arising.com.au/aviation/windturbines/wind-turbine.html.

[73]Medici, D., "Wind Turbine Wakes—Control and Vortex Shedding," KTH Mechanics Royal Institute, 2004: http://www.diva-portal.org/smash/get/diva2:9439/FULLTEXT01.pdf.

Both the FAA[74,75,76] and United Kingdom (UK) Civil Aviation Authority (CAA)[77,78] have directives that establish separation criteria due to the danger of wake turbulence on departing/arriving aircraft as well as recommendations for avoiding airborne turbulence below and downwind from aircraft, especially larger aircraft.

Chapter 7 of the FAA *Aeronautical Information Manual (AIM)* provides the following description of wake vortex characteristics in Section 3, "Wake Turbulence":

- The vortex circulation is outward, upward and around the wing tips when viewed from either ahead or behind the aircraft. Tests with large aircraft have shown that the vortices remain spaced a bit less than a wingspan apart, drifting with the wind, at altitudes greater than a wingspan from the ground. In view of this, if persistent vortex turbulence is encountered, a slight change of altitude and lateral position (preferably upwind) will provide a flight path clear of the turbulence.
- Flight tests have shown that the vortices from larger (transport category) aircraft sink at a rate of several hundred feet per minute, slowing their descent and diminishing in strength with time and distance behind the generating aircraft. Atmospheric turbulence hastens breakup.
- When the vortices of larger aircraft sink close to the ground (within 100 to 200 ft.), they tend to move laterally over the ground at a speed of 2 or 3 knots.
- There is a small segment of the aviation community that have become convinced that wake vortices may "bounce" up to twice their nominal steady state height. With a 200-ft. span aircraft, the bounce height could reach approximately 200 ft. AGL. This conviction is based on a single unsubstantiated report of an apparent coherent vortical flow that was seen in the volume scan of a research sensor. No one has determined the conditions that cause vortex bouncing, how high wake vortices bounce, at which angle they bounce, or how many times they may bounce. On the other hand, no one has determined in certain terms that vortices never bounce. Test data have shown that vortices can rise with the air mass in which they are embedded. Wind shear, particularly, can cause vortex flow field "tilting." In addition, ambient thermal lifting and orographic effects (rising terrain or tree lines) can cause a vortex flow field to rise.
- A crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex. Thus, a light wind with a cross-runway component of 1 to 5 knots could result in the upwind vortex remaining in the touchdown zone for a period of time and hasten the drift of the downwind vortex toward another runway.

To put this into perspective, the FAA ATC is required to provide 2-minute separation of aircraft taking off and landing to avoid wake turbulence, reflecting its treatment as a severe danger to aircraft.

3.2.3 Characterizing and Managing Impacts

3.2.3.1 Radar

DOE recently collaborated with the DoD, DHS, and FAA in sponsoring the IFT&E Program to validate commercial off-the-shelf (COTS) technologies with the potential to mitigate electromagnetic interference from WTGs on radar systems.[79] The IFT&E Program Team formed in June 2011 and operated through approximately October 2013, led by the Sandia National Laboratories (for expertise in wind energy deployment) and the Massachusetts Institute of Technology (MIT) Lincoln Laboratory (for expertise in radar technology analysis). Additionally, though not a primary partner, the National Oceanic and Atmospheric Administration (NOAA) provided weather data and aircraft support. The three stated goals of the IFT&E Program are as follows:[80]

1. Characterize the impact of wind turbines on existing Air Surveillance Radars.
2. Assess near-term mitigation capabilities proposed by industry.
3. Collect data and increase technical understanding of interference issues to advance development of long-term mitigation strategies to determine future R&D priorities.

The IFT&E Program consisted of three 2-week flight campaigns near NAS radar systems in high-density WTG areas in Minnesota and Texas. In addition, nine private sector vendors that were selected by Sandia National Laboratories participated in the flight campaigns to test and evaluate candidate technologies. In each of the campaigns, MIT Lincoln Labs built an Adjunct Radar Analysis Processor (ARAP) that was reused (with modifications) at each test event to collect

[74] FAA, "Aeronautical Information Manual": http://www.faa.gov/air_traffic/publications/atpubs/aim/index.htm.
[75] FAA, "Pilot and Air Traffic Controller Guide to Wake Turbulence," April 1995.
[76] FAA, Order JO 7110.65U, "Air Traffic Control Section 9, Departure Procedures and Separation (with Changes)," February 9, 2012.
[77] UK Civil Aviation Authority (CAA), "Safety Sense Leaflet," January 2009: http://www.caa.co.uk/publications
[78] CAA, "NATS Aeronautical Information Circular (AIC)," P 18/2009, 26 March 2009: http://www.nats-uk.ead-it.com/public/index.php.html.
[79] IFT&E, "Interagency Field Test and Evaluation of Wind-Radar Mitigation Technologies—Summary," June 28, 2012.
[80] DOE, "Fact Sheets on the First and Second Test Results of the Interagency Field Test & Evaluation of Wind—Radar Mitigation Technologies," October 31, 2012, and April 30, 2013.

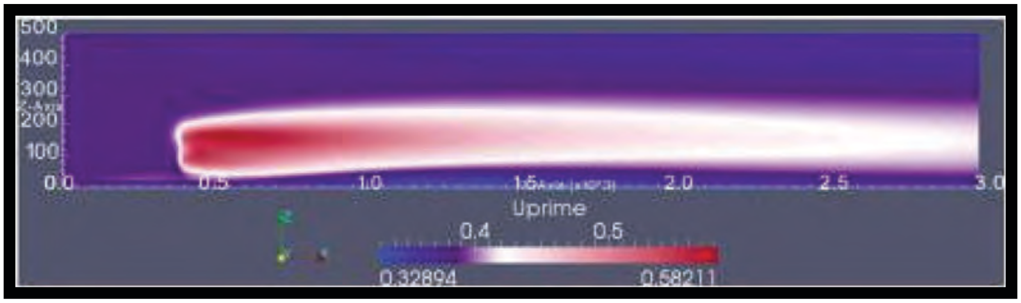


Figure 3.19. Fraunhofer simulation graphic.

detailed data from the federally owned NAS radar systems.[81] Sandia National Laboratories worked with participants from the wind energy industry to track weather conditions and gather data from WTGs in the test area, including individual turbine circumstances (e.g., rotation rate, blade angle, nacelle direction) as well as static turbine specifications before and during the tests. Multiple types of government and private aircraft were flown at each test event, using a GPS tracker to establish positional accuracy data. In order to preserve credibility across the field stakeholders, no flight information (e.g., aircraft type, speed, route, etc.) was provided to NAS radar operators or technology vendors.

All three flight campaigns were completed by the publication of this Guidebook but data analysis was completed for only the first two campaigns. Once the IFT&E Program Team finalizes the data analysis and reports for all three tests, results will be distributed to the sponsoring federal agencies. The individual test results and associated recommendations are expected to achieve the following objectives:[82]

- Accelerate the adoption of mitigation technologies by the radar community.
- Allow the sponsor agencies to make near-term and future investment decisions.
- Provide government agencies quantitative WTG interference data that can be used by government researchers to develop new mitigation technologies.
- Provide additional insights and a deeper scientific understanding into the phenomenology of wind turbine interference on radar systems for all stakeholders.
- Encourage participants to use their proprietary information garnered during the tests for product improvements.

3.2.3.2 Turbulence

Beyond siting guidance that can be extracted from field and modeling studies summarized in Section 3.2.2.3, a turbulence modeling tool developed by the Fraunhofer Institute for Wind Energy and Energy System (i.e., Simulation of Wind Farm Effects on Light Aircraft) may be helpful in evaluating the potential effects of projects sited near airports and aircraft activity areas.[83] The model is reported to compute how wind power plants influence aircraft at various wind speeds and wind directions. The model allows users to input a variety of turbine parameters and evaluate the effects of two different wind speeds and up to five aircraft flight trajectories. The Fraunhofer simulation, shown in Figure 3.19, demonstrates the turbulence generated by wind turbines. The red area shows heavy turbulence, which is common near wind farms.

In the area of research, a new WTG turbulence study was commissioned in July 2013, conducted jointly by Sandia National Laboratories and Texas Tech University Scaled Wind Farm Technology Facility, located at the Reese Technology Center in Lubbock, TX. It is expected to provide a wide array of "research opportunities for [the] study of turbine-to-turbine interactions"[84] and to provide the most detailed studies available on complex wind farm aerodynamics. Sandia has developed an innovative LIDAR-based system that will be able to gather turbulence data in large volume spaces. Due to its proximity to Reese Air Force Base, this facility may also be useful in studying the effects of WTG turbulence on aircraft.

3.2.3.3 Agency Siting Guidance

As noted in the American Wind Energy Association (AWEA) Siting Guide, "Consultation with a number of federal agencies

[81] DOE, "Fact Sheets on the First and Second Test Results of the Interagency Field Test & Evaluation of Wind—Radar Mitigation Technologies," October 31, 2012 and April 30, 2013.

[82] IFT&E, "Interagency Field Test and Evaluation of Wind-Radar Mitigation Technologies—Summary," June 28, 2012.

[83] Pele, Anne-Francoise, "Simulations show pilots should steer clear of wind farms," 2012: http://www.eetimes.com/electronics-blogs/other/4395549/Simulating-wind-farm-risks-for-ultra-light-aircrafts.

[84] Barone, M. and J. White, "Scaled Wind Farm Technology Facility: Research Opportunities for Study of Turbine-Turbine Interaction," Sandia National Laboratories, SAND2011-6522.

that have jurisdiction over radar systems is often part of obtaining regulatory approvals. As part of its hazard determination . . . the FAA engages other agencies to review a project that has filed an NPC (Notice of Proposed Construction)".[85] Key agencies of interest here include DoD, DHS, the National Telecommunications and Information Administration (NTIA) Interdepartment Radio Advisory Committee (IRAC), and NOAA.

The AWEA Siting Guide specifically notes that if a project is to be sited near an area of concern, "a developer is advised to contact the DoD Siting Clearinghouse in order to de-conflict early in the planning process. The DoD Siting Clearinghouse provides a 'one-stop shop' for comprehensive, expedited evaluation of energy projects and their potential effect on DoD operations. The Clearinghouse's formal review process applies to projects filed with the Secretary of Transportation, under Title 49 USC Section 44718 (pertaining to the FAA's obstruction evaluation process), as well as other projects proposed for construction within military training routes or special use airspace, whether on private, state, or federal property (e.g., land managed by the Bureau of Land Management [BLM]." The DoD Siting Clearinghouse mission is to protect DoD mission capabilities from incompatible development by collaborating with DoD Components and external stakeholders to prevent, minimize, or mitigate adverse impacts on military operations, readiness, and testing. The DoD Siting Clearinghouse acts as the conduit between the FAA's Obstruction Evaluation Review Process and the wind developer. Operational impacts of wind turbines on DoD missions are determined in parallel by several DoD organizations using differing methods and multiple modeling tools, none of which are available for public view.

DoD has collaborated with the Natural Resources Defense Council (NRDC) to publish a guide for working with the DoD on siting renewable energy development.[86] The goal of the primer is to identify key considerations for siting renewable energy projects that could affect military operations. Additionally, the DoD Office of Economic Adjustment, through the Defense Economic Adjustment Program, provides both technical and financial assistance to state and local governments through the Joint Land Use Study (JLUS) process[87] to collaborate with the local military to plan and carry out strategies promoting compatible civilian use adjacent to installations, ranges, military training corridors, and special use airspace. This community-driven, cooperative planning process results in a strategic plan and specific implementation actions to ensure that civilian growth and development are compatible with vital training, testing, and other military operations. The JLUS process promotes and enhances civilian and military communication and collaboration, serves as a catalyst to sustain the military mission, and promotes public health, safety, quality of life, and economic viability of a region. Finally, the DoD Readiness and Environmental Protection Integration (REPI) Program[88] assists identification of innovative land conservation solutions that protect and benefit military readiness and sensitive environmental habitats, while promoting feasible alternatives to otherwise intractable wind turbine generation development near military installations, special use airspace, and military training routes.

3.2.4 Meteorological Evaluation Towers

Meteorological Evaluations Towers (METs) also present unique challenges to aviation. Wind power developers erect METs during project siting to investigate the viability of physical land areas to support a commercial wind project. METs record the on-site wind speed, typically for at least 1 year, and the data is then assessed to predict how much electricity the project site could support. The towers utilize anemometers (i.e., wind sensors) at several different heights above ground level to evaluate the wind resource. Taller towers provide more accurate data for evaluating wind at the height of the rotor, which can be 300 to 400 ft. AGL, but shorter towers are more cost effective in the preliminary project stages.

Wind developers often erect towers at heights below 200 ft. in order to avoid filing a Form 7460 application with the FAA, which also prevents their competitors from easily identifying potential project locations and allows them complete flexibility over the process without FAA regulation. Further complicating the issue, wind farm sites are often in rural areas that are regularly used by small aircraft, which may be flying at low altitude. In addition to recreational pilots, businesses and public service providers may be operating aircraft at low altitudes and at risk of collision with METs, including agriculture applicators, aerial fire suppression, helicopter emergency medical services, animal damage control operations, fish and wildlife surveys, and law enforcement operations.

Figure 3.20, courtesy of the National Agricultural Aviation Association (NAAA), shows a 198-ft. tall MET located within the wind farm. In this case, the wind turbines are visible to pilots, but prior to construction, the MET stood alone on the landscape and would have been difficult to detect in isolation.

[85] American Wind Energy Association (AWEA), "Wind Energy Siting Handbook," Para 4.1.6, pp. 4-20 to 4-22, February 2008.

[86] U.S. Department of Defense (DoD), National Resources Defense Council (NRDC), "Working with the Department of Defense: Siting Renewable Energy Development," September 2013: http://www.acq.osd.mil/dodsc/library/Siting_Renewable_Energy_Primer_5SEP13_FINAL_WEB.pdf.

[87] DoD, Office of Economic Adjustment (OEA), "About Compatible Use: Joint Land Use Study—JLUS": http://www.oea.gov/programs/compatible-use/about.

[88] DoD, Readiness and Environmental Protection Integration (REPI), Program Website: http://www.repi.mil/.

Figure 3.20. 198-foot MET within a wind farm array.

When METs are erected at heights below 200 ft. AGL, they are not painted or lit in a manner that can be seen easily by pilots. In fact, the towers are narrow, unmarked, and grey in color, making them very difficult to see in day and invisible at night. While FAA regulations related to marking of such structures are undefined, this aviation safety problem has been identified in other countries, including Canada and the United Kingdom.

- **UK CAA—**Civil Aviation Publication (CAP) 764, "CAA Policy and Guidelines on Wind Turbines" states that wind power developers "be aware that anemometer masts are often difficult for pilots to acquire visually, and so aviation stakeholders may assess that individual masts should be considered a significant hazard to air navigation and may request (either during the planning process, or post-installation) that masts be lit and/or marked." [89]
- **Transport Canada—**Advisory Circular No. 600-001, "Marking of Meteorological Towers," states, "it is not feasible for Transport Canada to regulate the application of marking and lighting of all objects that might be encountered by pilots who choose to engage in a specialized activity that involves flight very low to the ground. Most of these objects are of natural origin (e.g., trees). The MET, however, is a structure that is under the control of the wind farm company. In as much as there is control, it would seem both reasonable and prudent to apply marking because of the adverse impact the tower may have upon the known activity of crop spraying. Here we are considering only marking, since crop spraying does not occur at night.[90]

In the United States, the National Transportation Safety Board (NTSB) recently issued a safety recommendation regarding METs in a letter dated May 15, 2013.[91] The letter recommended that the Department of Agriculture (USDA), Department of Interior (DOI), and DoD provide or direct applicants for METs on federal lands to information contained in FAA AC 70/7460-1, "Obstruction Marking and Lighting." The NTSB also included safety recommendations to the FAA, AWEA, and all 50 state governments and the District of Columbia to advise applicants in a similar manner. It recommends that the FAA establish MET lighting requirements[92] and develop a national MET database. The NTSB proposes that the AWEA revise its handbook to clearly indicate the hazards that METs pose to low-altitude operations and encourage marking them to improve visibility. It also proposes that states, District of Columbia, Puerto Rico, Northern Mariana Islands, Samoa, and the Virgin Islands should enact legislation requiring that METs be marked and registered in a directory. Finally, the NTSB sent letters asking other stakeholders to take an active role in educating wind energy developers on the dangers METs pose, enacting legislation, and marking/lighting METs.

The NTSB's actions suggest that a 2011 FAA policy statement[93] recommending that METs be marked is not strong enough.[94] In issuing the safety recommendations, the NTSB concludes that, "due to their rapid construction and lack of conspicuity, METs pose a threat to pilots who conduct low-altitude operations and that the required registration, marking, and—where feasible—lighting of these structures would aid pilots in avoiding them." It also pointed out that the lack of federal requirements has led 10 states to take action on the threat to aviation safety of METs as short as 50 ft. AGL. Four states (Montana, Nebraska, North Dakota, and Wyoming) require all MET locations to be registered and the towers marked. Five states (California, Idaho, Kansas, Mississippi, and South Dakota) require that METs be clearly marked.

3.2.5 Offshore Wind

While there are currently no wind turbines constructed in U.S. waters, offshore wind farm development is expected over the next 5 to 10 years. The first offshore wind farm was constructed in Danish waters in 1991 and currently there are over a 1,000 wind turbines operating in marine waters in

[89]CAA, "CAP 764, CAA Policy and Guidelines on Wind Turbines," Chapter 2, paragraph 10.3, p. 9, July 2011.

[90]Transport Canada, Advisory Circular No. 600-001, "Marking of Meteorological Towers," March 3, 2011: http://www.tc.gc.ca/eng/civilaviation/opssvs/managementservices-referencecentre-acs-600-600-001-1276.htm.

[91]National Transportation Safety Board (NTSB), "Safety Recommendation Letter to the FAA," Sections A-13-16 and A-13-17, May 15, 2013.

[92]Spence, Charles, "NTSB wants meteorological towers marked," *General Aviation News*, 23 May 2013: http://www.generalaviationnews.com/2013/05/ntsb-wants-meteorological-towers-marked/.

[93]Federal Register, Vol. 76, No. 3, "Proposed Revision to FAA Advisory Circular on Marking Meteorological Evaluation Towers," pp. 490–491, FR Doc No. 2010-33310, January 5, 2011.

[94]NTSB, "Safety Recommendation Letter to the FAA," May 15, 2013.

Timeline for Regulation of METs

- December 15, 2003—An Erickson SHA Glasair TD aircraft collided with an unmarked and unlighted MET during VMC conditions near Vansycle, Oregon. The aircraft was destroyed and both occupants sustained fatal injuries.
- May 19, 2005—An Air Tractor AT-602 agricultural airplane was destroyed upon impact with terrain after a collision with an unmarked and unlighted MET (originally recorded as an antenna tower, but later revised) near Ralls, Texas, fatally injuring the pilot in VMC conditions.
- January 5, 2011—The FAA published a notice seeking comments on a proposed revision to AC 70/7460-1, "Obstruction Marking and Lighting," requesting comment on the establishment of "a uniform and consistent scheme for voluntarily marking" METs less than 200 ft. AGL.
- January 10, 2011—A Rockwell International S-2R agricultural aircraft was severely damaged and the pilot fatally injured after it struck an unmarked and unlighted MET in VMC conditions on Webb Tract Island, Oakley, California.
- March 6, 2011—The NTSB issued a Safety Alert (SA-016) on METs, urging pilots to be vigilant around them. The Safety Alert also provided background information on accidents, the status on regulatory policy, and encouraged the marking of METs.
- June 24, 2011—The FAA published a policy statement with its recommendation for the voluntary marking of METs erected in remote and rural areas that are less than 200 ft. AGL and that landowners and developers use guidance contained in Advisory Circular 70/7460-1, "Obstruction Marking and Lighting" for such voluntary marking. It stated that lighting is not necessary because agricultural operations are performed during daylight. It also stated that it is infeasible for the FAA to maintain a national database for structures that are less than 200 ft. AGL.
- August 27, 2012—California Gov. Jerry Brown signed legislation requiring towers "standing 50 feet and taller to be clearly marked with bright aviation colors." The new rules will apply to towers built after January 1, 2013 and will "sunset" in five years.
- May 15, 2013—The NTSB issued a "Recommendation Letter" (described previously) to the FAA.

Europe and China. It is important to understand the potential impacts of this construction on airports and aviation. Experience in Europe offers some guidance for evaluating issues in the United States.

The potential issues identified in the United Kingdom are similar to those on land-based wind turbines: Obstacle Avoidance (e.g., WTGs, METs); Electromagnetic Interference (e.g., radars, NAVAIDs, communications systems); WTG-Induced Wake Turbulence; and the government missions that these concerns affect (e.g., aviation safety, unimpeded air surveillance for national security). Given the geographic nature of the British Isles, helicopter routes have been in use in the North Sea and Morecambe Bay for many years and guidance recommends against siting offshore wind turbines within 2 nautical miles (NM) of any helicopter main route (HMR). Helicopter traffic has also been common in support of building and maintaining offshore oil platforms and guidance states that installations within 9 NM of such a platform can pose an aviation safety risk.

DoD works with the Bureau of Ocean Energy Management (BOEM) to ensure that offshore wind resource development is compatible with military training, testing, and operations on the Outer Continental Shelf. BOEM and DoD are working collaboratively with other federal agencies and state governments to plan for low-conflict offshore renewable energy development.

The Cape Wind Project located south of Cape Cod, Massachusetts, offers some insight into the application of FAA review processes for an offshore wind project. Cape Wind obtained a determination of no hazard from the FAA in August 2012, which included four conditions: (1) a requirement of notice of construction beginning, (2) a $15M escrow to replace an upgraded radar (after a study indicated an unacceptable level of performance) if it did not fully mitigate the interference/clutter issue, and (3 and 4) two lighting and marking conditions (temporary and permanent). Three particularly remarkable items a developer should notice in reviewing the full text of this study include the following:

- The general note stating that, "A Probability of Detection (PD) of 0.9 (90%) or better is desirable. For most

Figure 3.21. Fire Island wind farm and Ted Stevens Anchorage International Airport.

search radars, a PD of 0.8 (80%) or better is considered satisfactory."

- The remark on Section 91.119, "Minimum Safe Altitudes" that "provides that no person may operate an aircraft at an altitude of 500 [ft.] AGL except over open water or sparsely populated areas." Additionally, "aircraft may not be operated closer than 500 ft. to any person, vessel, vehicle, or structure," which certainly applies to offshore wind energy projects.
- A final statement that "Under Part 77 the FAA does not consider impacts to emergency operations in an aeronautical study because they would not occur on an ongoing or regular basis and, therefore do not reach the level that could be considered significant." Upon initial analysis, this statement conflicts with an earlier Recommended Practice Example and considerations used in the United Kingdom to evaluate overall acceptability.

3.2.6 Case Study: Fire Island Wind Farm and Anchorage International

Fire Island, located west of Ted Stevens Anchorage International Airport (ANC), is the location of Alaska's first commercial wind farm that went into service in the fall of 2012. Figure 3.21 shows the geographic proximity of the wind farm and the airport. Fire Island provides an interesting case study of the impacts of wind turbines on airspace and the process of evaluation and mitigation.

A private development company proposed a wind project on Fire Island in the early 2000s and an application to the FAA included 36 WTGs. The FAA conducted an aeronautical study under provision of U.S. Code, Title 49, section 44718 and Code of Federal Regulations, Title 14, part 77.[95] The evaluation

[95] FAA, Aeronautical Study No. 2004-AAL-104-OE, 2008.

study scrutinizes the impact of wind turbines on (a) airport facilities; (b) operations; (c) procedures; (d) physical, electromagnetic, and visual interference on navigation and navigational aids; and (e) airport capacity. The impacts identified by the FAA included the following:

- Of the original 33 turbines, 22 exceeded 600 ft. above mean sea level (MSL), as per Part 77, Section 77-3 (a). These 22 turbines would have affected the CAT III Instrument Landing System (ILS) instrument approach procedure into ANC.
- VHF Omnidirectional Radar (VOR) and ASR-8 radar at ANC would have experienced adverse effects due to electromagnetic interference (EMI), wind turbine height, and wind blade turbulence.
- Wind turbulence would have led to unsafe departure for small aircrafts if they were to adhere to the departure procedures. (Note: Wind turbulence was not part of the scope of the aeronautical study).
- No impacts would have been incurred upon long-range surveillance radars.

In 2008, the FAA approved a 24-turbine project, objecting to the other 12 turbines due to airspace impacts. Even the 24-turbine approval required a number of mitigation measures to preserve the airspace capabilities at ANC, including the following:

- The FAA required that the height of five of the 24 WTGs must be decreased because no wind turbine can have height above 600 ft. MSL and mast height above 250 ft. MSL.
- A new VOR was constructed on the mainland near the airport and the old VOR was decommissioned. To address VOR EMI, Doppler VOR replaced conventional VOR. This specific change in technology allows for broader changes in approach/departure procedures to improve air traffic management.
- Wind turbulence effects warranted replacement of ASR-8 with ASR-11.
- VFR aircraft departing/arriving Anchorage area avoiding Anchorage Class C airspace were restricted from flying over Fire Island on northbound routes. Fire Island was reclassified as "congested" airspace, requiring planes to stay 1,000 ft. above the tallest structures on the island.
- All structures were required to be marked and/or lighted in accordance with FAA AC 70/7460-1K,[96] including white paint and synchronized red lights.

[96]FAA, Advisory Circular 70/7460-1K, Chg. 2, "Obstruction Marking and Lighting," Chapters 4, 12, and 13: http://www.faa.gov/regulations_policies/advisory_circulars/index.cfm/go/document.information/documentID/74452.

Since 2008, 11 of the wind turbines have been constructed and currently generate enough electricity to power an average of 5,600 homes.

3.2.7 Lessons Learned

While some energy technologies have not been closely evaluated for potential impacts on aviation, this is not the case for wind energy. Due to its capacity to produce a significant amount of renewable energy and achieve public policy mandates for renewable energy, high demand to construct wind projects has forced aviation and military stakeholders to respond to encroachment on the NAS, garnering wind energy installations close scrutiny since at least 2006.

The lesson of wind energy and aviation has been the need to compromise. Wind energy provides important benefits for national security, economics, and the environment. However, airspace is a finite resource, central to supporting commercial and recreational aviation, emergency response, and military readiness. Project development is subject to a review process facilitated by the FAA and contributed to by the military and other government agencies with a variety of interests. Through that process, individual projects must demonstrate how they are avoiding and minimizing impacts on airspace and, if required, how they will mitigate for unavoidable impacts. The approval may be an opportunity to restrict airspace around the wind farm and enhance airspace in areas where the supporting system needs improvement.

After about 10 years of active dialogue on the matter, research and compromise will continue to be necessary. The DOE, FAA, DHS, and DoD have taken lead roles in this process, as evidenced by the IFT&E Program and its focus on developing radar mitigation technologies that can be deployed throughout the country. Interagency coordination, building on successful projects like the DoD Siting Clearinghouse, will be important for avoiding and mitigating potential problems early in the process.

3.3 Oil and Gas Drilling

3.3.1 Research Context

Advances in technology used to extract oil and natural gas from subsurface reservoirs have recently produced a boom in production. Previously, reserves trapped in shale formations, which are typically narrow bands of tightly packed sedimentary rock, were not economically productive. Over the past decade, two important breakthroughs have facilitated the cost-effective removal of these shale reserves. The first advancement is the optimization of horizontal directional drilling, a technique created as an effective way to install underground conduits such as water lines and electrical cables, to extend the drill bit into

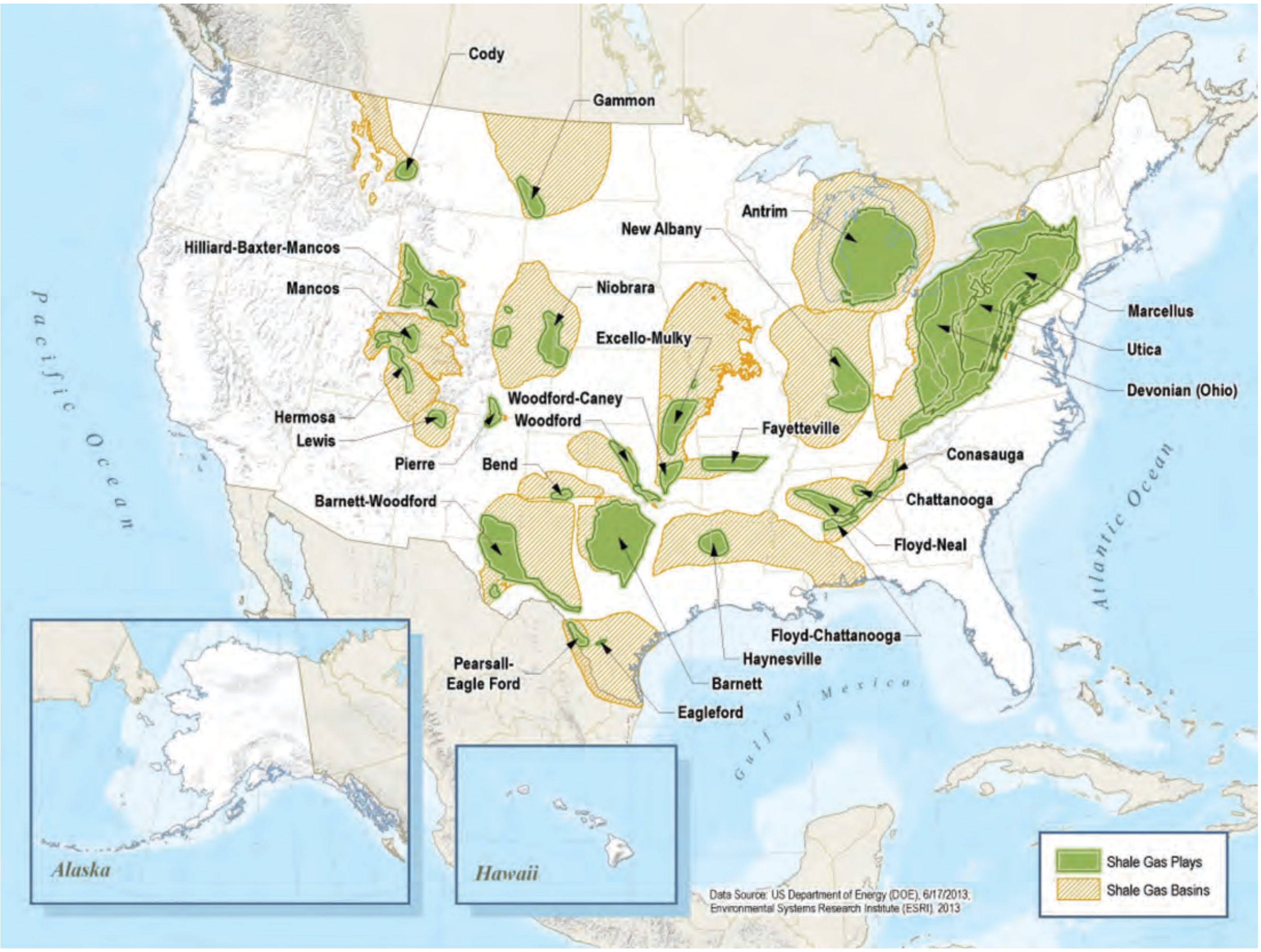


Figure 3.22. U.S. shale gas resources.

the narrow reservoirs and parallel to the above-ground surface. The second advancement is expansion in hydraulic fracturing, a process where water, chemicals, and sand are injected into the shale to break it apart and release the oil and gas product. These new techniques are sometimes referred to as unconventional production, whereas conventional production is distinguished by well drilling into a reserve where oil and gas readily flow to the wellbore. Much of the reserves that are released are in the form of gas (i.e., dry reserves) though some less mature product includes some oil as well (i.e., wet reserves).

According to the U.S. Energy Information Agency (EIA), dry shale gas expanded four-fold between 2006 and 2010, constituting 23% of total gas production. Wet gas reserves composed an additional 21% of total domestic reserves. Of all the natural gas consumed in the United States in 2011, 95% was from domestic sources. Figure 3.22 shows shale gas reserves in the United States. Areas defined as "plays" are being actively explored. Due to the potential access to cleared flat land within some of the shale plays, many airports have been approached by energy companies about leasing land for exploration and extraction. Recent legislation under the "FAA Modernization and Reauthorization Act" of 2012 has provided communities that operate GA airports with enhanced flexibility to utilize oil and gas revenue for non-airport improvements.

CRITICAL RESEARCH NEED—Oil and Gas Drilling

Evaluate airport management of proposed oil and gas projects to date and use their lessons learned to inform guidance for future airport drilling projects.

3.3.2 What Are the Impacts of Oil and Gas Drilling?

Whether conventional or unconventional, drilling requires a number of similar facilities. The hydraulic fracturing (i.e., fracking) necessary to develop oil and gas from shale deposits requires additional support components. Figure 3.23 depicts some of the most common facilities.

First, a well pad is constructed, which provides a stable platform for facilities and activities during both construction and operations. The well pad is about 5 acres in area and can be reduced to about 3.5 acres to support long-term use.

Two types of drill rigs are most commonly used in current drilling programs. The larger is a Nomac Rig, which has a height of 173 ft. AGL. A smaller but less efficient rig is referred to as a mountain rig, which is 103 ft. tall. The rigs need to be able to drill into the ground to reach shale reserves, which are about 8,000 ft. deep. In comparison, shallow wells that are used to extract traditional reserves are closer to a few thousand feet below ground. The drill rigs are a temporary presence, as shale wells can be drilled over about a 30-day period. A "workover" rig, which is between 80 and 90 ft. tall, is then brought in to clean up and stabilize the well.

One of the unique components of the hydraulic fracturing process is the need for an abundance of purified water, which must be available over a very short period when the fracturing is conducted. This necessitates the construction of fracking ponds near well sites that can be pumped under pressure into the well over a 4 to 7 day period after the well has been drilled and worked over. The ponds at existing well sites near airports are about 3 acres in size. The frack ponds are only needed during the fracking process but are costly to

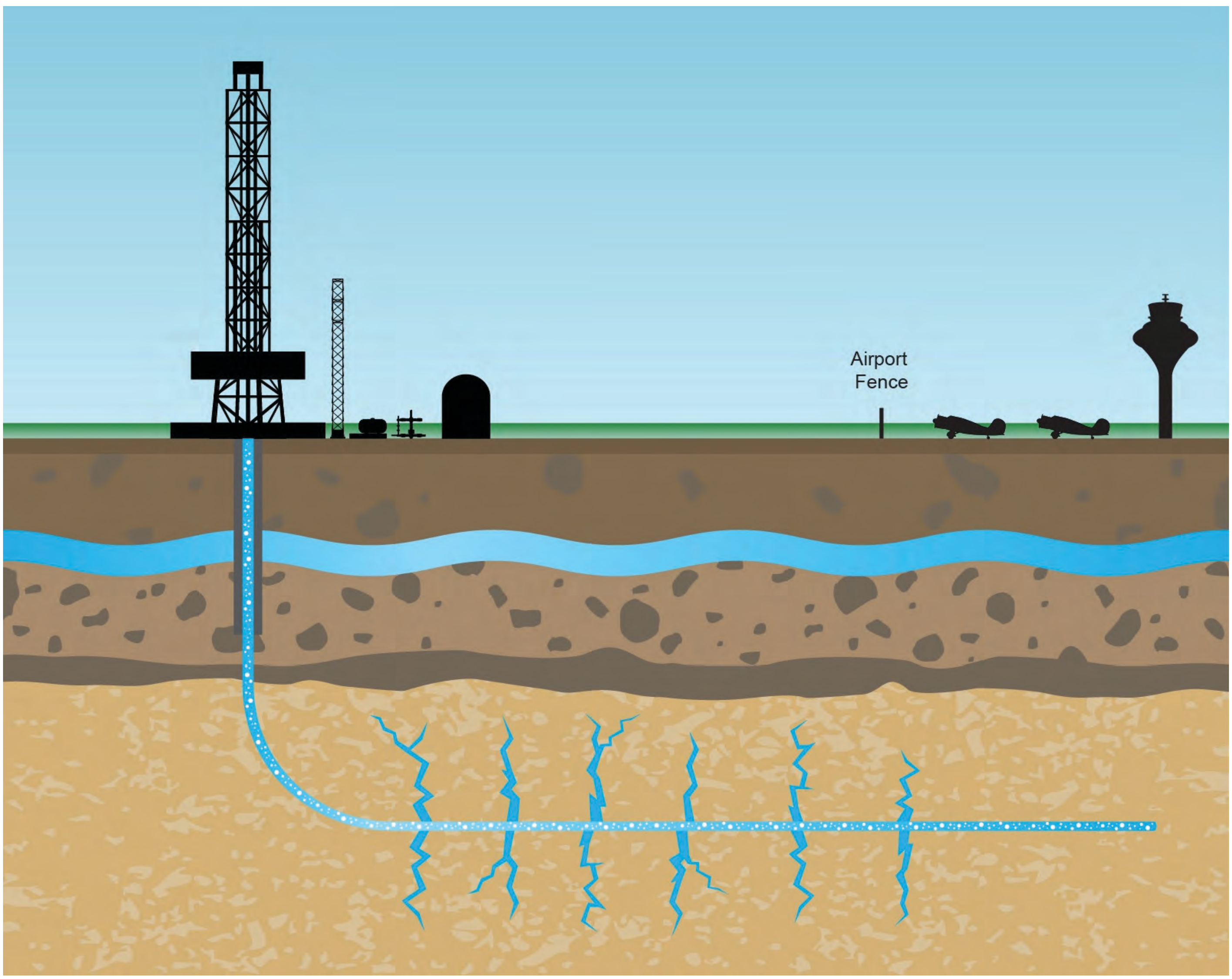


Figure 3.23. Typical facilities required for hydraulic fracturing.

develop and reclaim, and therefore are often reserved in place for future fracking operations.

The infrastructure that is left in place on the well pad after construction is relatively low profile and non-intrusive. The actual wellhead consists of some pressure valves that are about 8 ft. above the ground. Separation tanks used to remove other fluids from the product are about 5 ft. tall. Storage tanks that provide temporary storage of separated product can be 12 ft. tall. The tallest structure on a typical fracking installation is a communication tower, which can be as high as 50 ft. AGL to facilitate remote monitoring of production activities. Other components of a wider drilling network include a compressor station that pressurizes the gas for delivery through a regional gas pipeline delivery network, a water pipeline network for delivery of water to the frack ponds, and deep injection wells that are used for discharging process water after it is used and collected post-fracturing.

Once the drilling pad is constructed along with all other supporting infrastructure, the drill rig is erected. Drilling takes about 30 days. Then a workover rig is brought in to clean and stabilize the well, often including the flaring of excess gas, lasting up to one week. Then the well is fracked over the next 4 to 7 days and, finally, the well is put into production.

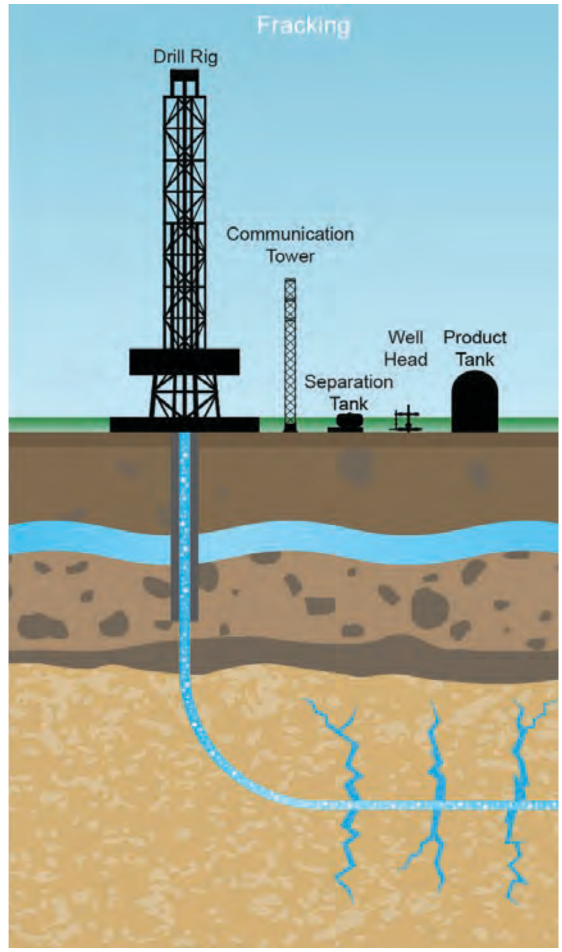


Figure 3.24. Fracking structures.

3.3.2.1 Physical Penetration of Airspace

The airspace issues that arise from oil and gas development include physical penetration of the Part 77 imaginary surface during the drilling period and for permanent operational infrastructure, non-physical penetration associated with flaring of waste gas during the wells' development, and wildlife hazards associated with frack ponds.

Figure 3.24 depicts the relative size of various oil and gas development infrastructure against a generic airspace surface. Physical penetration of airspace is most significant in association with the drill rigs. Temporary penetration of airspace is commonly approved by the FAA through the filing of a Form 7460, typically when a crane is needed for construction. However, such approvals are only provided when there is no other practical alternative. When conventional drilling is proposed, the energy company may be able to justify the need to locate a well rig closer to the airport so that the wellbore reaches an area where the oil or gas resources are more accessible. The capability of horizontal directional drilling with its ability to access reserves horizontally diminishes the need to locate above-ground infrastructure closer to a reserve, although cost may be considered as part of an alternative analysis. When the drilling company determines that it will benefit from locating the drill rig closer to airport infrastructure, it may choose to deploy the shorter mountain rig. At 70 ft. shorter than the Nomac rig, the mountain rig can potentially be sited as much as 500 ft. closer to the airport, assuming the 7:1 set-back ratio that establishes the approach surface (see "Obstruction Height Zones" under Section 2.5).

The permanent facilities associated with oil and gas drilling are considerably shorter and unlikely to produce airspace issues. At about 50 ft. tall, the communications tower may represent a physical penetration or even obstruct radar signals, both of which would necessitate an airspace review by the FAA. The other structures occupying the drilling pad are typically 12 ft. tall or less and are thus inconsequential to airspace.

3.3.2.2 Flaring

A non-physical penetration issue associated with oil and gas drilling is the process of gas flaring (Figure 3.25 is an example). Flaring is conducted during the development of oil and gas wells for several reasons. In some cases, gas is flared off because it is considered waste product when the primary reserve may be oil. In other cases, the gas is being released during well testing and stabilization and, therefore, must be flared as part of the process of establishing and confirming

Figure 3.25. Gas well flaring.

the well's development. Regardless of the reason, customary practice for flaring is to erect a temporary stack and direct the gas through the stack for combustion. Beyond the physical height of the structure, there are potential non-structural impacts from the flame and the heat levels above the flame. The height of impact is not well understood for several reasons, including the fact that the height of the flame will vary based on the characteristics of the gas being combusted and the height of thermal impacts above a visible flame is difficult to characterize.

3.3.3 How Are Impacts Characterized and Managed?

In the oil and gas area, much of the understanding of potential impacts on airports and airspace has been gained as the result of reviewing individual project proposals. This experience has helped inform FAA guidance, as described below.

3.3.3.1 Projects at Airports

Airports offer favorable site conditions for the exploration and development of oil and gas facilities. The cleared and open management of land facilitates easy access over the land for exploration and development. There is ready access to infrastructure that support testing and development. Airports also provide energy companies ease of partnership in executing a single lease for one large property, rather than assembling a patchwork of landowners. Additionally, airports are favorable to consideration of business offers to lease land for oil and gas development as an alternative revenue source. Table 3.2 provides an unofficial list of airports where oil and gas drilling activities have occurred.

When Denver International Airport (DEN) opened in 1995, its land area included 49 pre-existing mineral oil and gas wells. (Another 25 wells were closed and capped due to the airport's construction.) By 2010, 27 additional well leases had been approved and developed, totaling 76 active wells. All current wells are vertical, although there has been interest in

Table 3.2. Unofficial list of airports with oil and gas drilling activities.

Airport	Code	State	Airport	Code	State
DENVER INTL	DEN	CO	STROTHER FIELD	WLD	KS
GREELEY-WELD COUNTY	GXY	CO	JEFFERSON COUNTY AIRPARK	2G2	OH
FRONT RANGE	FTG	CO	WHEELING OHIO CO	HLG	OH
DURANGO-LA PLATA COUNTY	DRO	CO	INDIANA COUNTY/JIMMY STEWART FLD	IDI	PA
ANTHONY MUNI	ANY	KS	BRADFORD RGNL	BFD	PA
SHALZ FIELD	CBK	KS	JOHN MURTHA JOHNSTOWN-CAMBRIA CO	JST	PA
GARDEN CITY RGNL	GCK	KS	DUBOIS RGNL	DUJ	PA
GARDNER MUNI	GDM	KS	JOSEPH A. HARDY CONNELLSVILLE	VVS	PA
GREAT BEND MUNI	GBD	KS	ROSTRAVER	FWQ	PA
HUGOTON MUNI	HQG	KS	PITTSBURGH INTL	PIT	PA
LIBERAL MID-AMERICA RGNL	LBL	KS	ALLEGHENY COUNTY	AGC	PA
MEDICINE LODGE	K51	KS	NEW CASTLE MUNI	UCP	PA
NEW CENTURY AIRCENTER	IXD	KS	DALLAS/FORT WORTH INTL	DFW	TX
PRATT RGNL	PTT	KS	JACK BROOKS RGNL	BPT	TX
TRIBUNE MUNI	5K2	KS	DENTON MUNI	DTO	TX
WELLINGTON MUNI	EGT	KS	ODESSA-SCHLEMEYER FIELD	ODO	TX

Sources: Direct inquiries by HMMH, Inc. and responses to a survey distributed by the FAA exploring horizontal wells to tap oil and gas potential under airport facilities. The airport's lease approvals addressed existing and future facilities including runway expansion to the north. All drilling sites are located outside of the Building Restriction Line. Permanent structures are relatively short (e.g., 15–20 ft. AGL). To perform maintenance on the wells, approximately every 18 months, companies must bring in large cranes (about 100 ft. tall), which are in place for up to 2 weeks. The companies must file a Form 7460 each time a crane is brought in for maintenance.

Jimmy Stewart Airport (IDI), a GA airport located in Western Pennsylvania, was approached by an energy company about drilling in 2006. Seven shallow wells (at a depth of 3,000 ft.) were drilled in 2008; one deep "Marcellus" well (8,000 ft.) was drilled in 2009. The rig was 142 ft. tall and was located 750 ft. from the edge of the runway. Two additional deep wells are proposed. The shallow wells were drilled in 7 days; the Marcellus well took 30 days. The FAA determination stated that the proposed facility would not affect IFR operations or penetrate Part 77 surfaces. A frack pond was constructed, and the water was used to frack the well and release the trapped gas. Once completed, the frack pond was reclaimed in accordance with FAA specifications. Figure 3.26 provides a photo of the drilling operations.

Figure 3.27 shows the location of airports in Western New York, Pennsylvania, and Eastern Ohio that overly the Marcellus Shale Play. While development of new gas wells has slowed over the past year due to a large supply and decreasing prices, discussions with several airports in this region suggest that they are fully aware of the natural gas drilling potential and see future business arrangements with energy companies as presenting an opportunity to develop alternative revenue sources.

Figure 3.26. Drill pad and frack pond at Jimmy Stewart Airport, PA.

3.3.3.2 FAA Oil and Gas Drilling Guidance

Oil and gas development, like other non-aeronautical activities, is subordinate to the public airport use of airport land at "federally obligated" airports. The FAA is in the process of finalizing an AC titled "Guidance on the Extraction of Oil and Gas on Federally Obligated Airport Property" to ensure that such activities are carried out appropriately. The specific purpose of the AC is (1) to assist airport sponsors by identifying applicable laws and regulations and FAA orders and guidance documents applicable to the FAA's review of proposed oil and gas activities and (2) to assist FAA Airports' field offices with the timely review of ALP changes, on-airport construction and airspace notification, Construction Safety Phasing Plan, environmental reviews, and applicable grant assurances for acceptable oil and gas development and operations on federally obligated airport property. The AC is informed by the FAA's oversight of proposed oil and gas development projects, including those implemented on airports such as DEN, IDI, and DFW.

In planning and approving oil and gas development, airport sponsors must ensure that:

- Oil and gas development does not conflict with current or planned aviation uses.
- Associated infrastructure meets airport design standards to ensure safe and continuous airport operations.
- Proposed infrastructure is identified on the ALP.
- Development conforms to applicable environmental standards and industry best management practices.
- Resulting revenue is collected and spent in accordance with the FAA's Revenue Use Policy and in compliance with grant assurances 24 and 25.

These requirements apply for both projects that are located on the surface of airport property, as well as those that penetrate into subsurface grounds below airport property. This has been referred to as a "behind the fence" project. However, projects with a surface presence on airport land have a significantly more complex involvement from the FAA.

The primary steps in the process are provided in Figure 3.28. In each step, the airport sponsor must ensure that the development project meets FAA requirements. It starts with notifying the FAA Regional Office and ADO about the proposed activity, ensuring that the terms of the lease meet both the subordination of the activity to aviation uses and procurement and financial equity obligations, and providing regular submissions to the FAA for each step in development to ensure that the project meets airport planning, safety, and environmental requirements. The AC spells out the process for both regional staff and airport sponsors. Some of the critical obligations associated with compatibility are provided below.

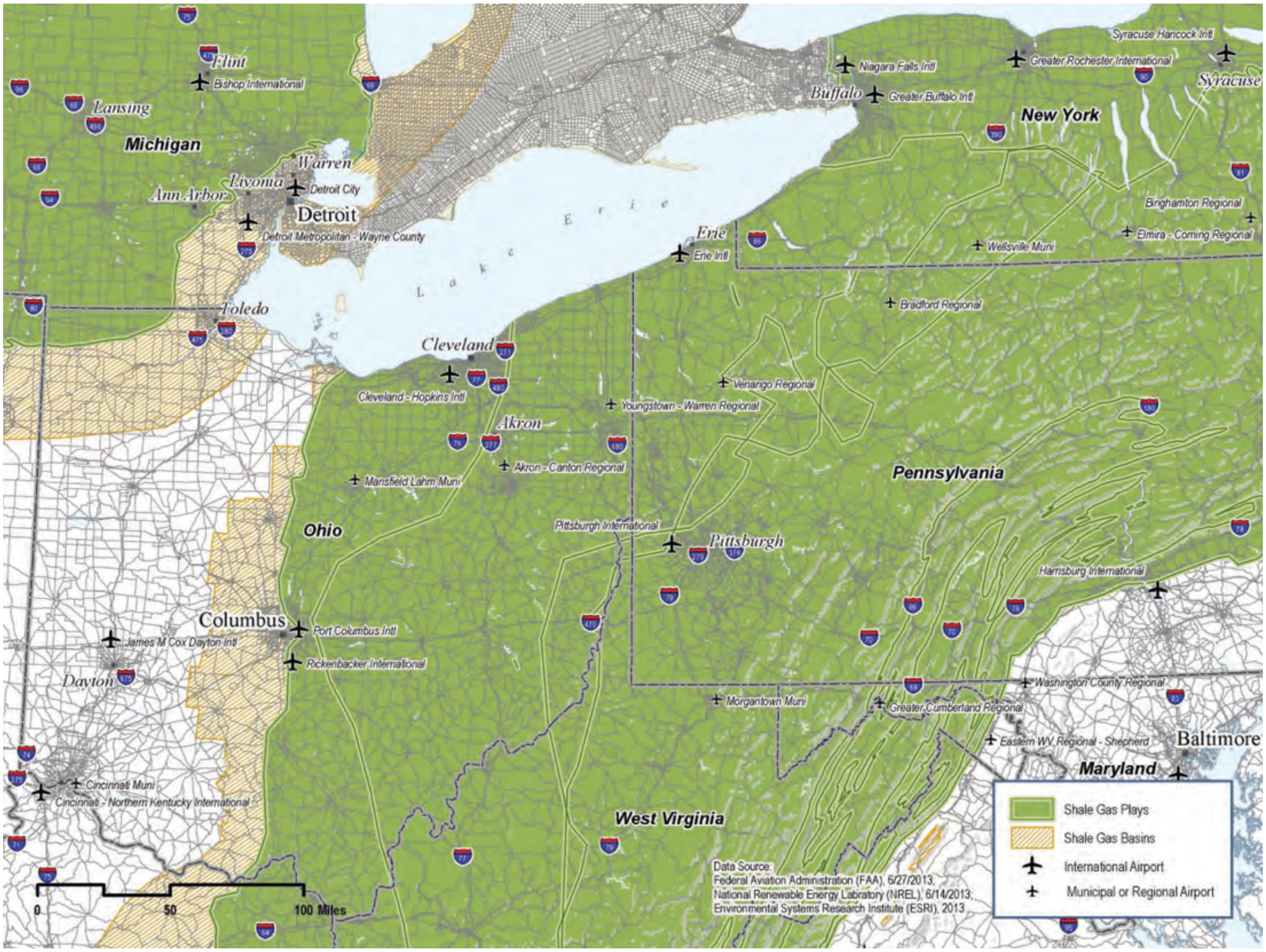


Figure 3.27. Airports located in the Marcellus Shale Play.

On-Airport Gas and Oil Development Requirements

Step 1
Identify Federal, State, and Local Regulations

Step 2
Development Planning
- Notify FAA Region/ ADO
- Provide Drawing of Development

Step 3
Draft an Acceptable Gas and Oil Lease

Prepare Lease to include:
- Subordination Clause
- Certification of Good Title
- Modification of ALP
- Documentation of Fair Market Value (FMV)

Step 4
Lease Solicitation and Determination of FMV
- Conduct Competitive Bid Process to Demonstrate FMV

Step 5
On-Airport Gas and Oil Exploration
- File Form 7460
- Modify ALP
- Obtain NEPA Sign-off

Step 6
Develop an Oil and Gas Production Plan
- File CSPP with FAA for Approval
- File Form 7460
- Modify ALP
- Obtain NEPA Sign-off

Step 7
Sponsor Signs Lease

Step 8
Individual Well Site Approvals
- Modify CSPP with FAA for Approval
- File Form 7460
- Modify ALP
- Obtain NEPA Sign-off

Step 9
Well Closure and Reclamation
- Modify CSPP With FAA for Approval
- Modify ALP
- Obtain NEPA Sign-off

Figure 3.28. Approval process for oil and gas drilling.

Hazard Mitigation: One of the common assurances that projects must meet is Hazard Mitigation.[97] Under this assurance, the design, construction, and operation of the project and related improvements (including fracking water ponds and wastewater management, drainage improvements, ditches, wetland mitigation, materials handling, landscaping, etc.) shall not create a hazardous wildlife attractant to the airport. FAA AC 150/5200-33 advises a 5,000 to 10,000 ft. separation distance between the airports Air Operations Area and a hazardous wildlife attractant. Additionally, the AC recommends that a 5-mile separation distance be considered when the attractant could cause wildlife movement into or across the approach or departure airspace. Existing frack ponds at DFW are subject to hazard wildlife mitigation requirements (see Section 3.3.4 below). For the single Marcellus well that was constructed at IDI, the energy company was required to reclaim the airport property after drilling to remove the frack pond due to its proximity to air operations areas.

Airport Layout Plans: Another common assurance that must be met is maintaining a current ALP.[98] The assurance requires the sponsor to update the ALP for any proposed changes where aeronautical uses are transferred to non-aeronautical uses, or where above-grade structures are constructed (including surface roads). Such updates must be submitted to the FAA for approval. The following oil and gas extraction facilities should be included on the ALP:

- Well pad sites.
- Well heads, including injection wells.
- Fracturing fluids storage pits and ponds.
- Dehydrator and compressor stations.
- Access roads.
- Other buildings or facilities.
- Other leased areas.

Oil and gas infrastructure associated with distribution of product to off-airport facilities must also be identified on the ALP and may include:

- Transmission lines.
- The collection and distribution of extracted fluids.
- Collector oil and gas pipelines.
- Fracturing fluid pipelines.
- Utilities serving the well site.

Because the exact location of these facilities will not be identified during planning stages when the FAA is reviewing the project, the ALP should specify facilities and areas. Once facilities are constructed, the ALP can be changed to show the as-built locations. The approval of the ALP update means that the sponsor can proceed with obtaining other regulatory approvals, such as an airspace safety determination or approval under the National Environmental Policy Act (NEPA). The approval of the ALP is considered a federal action, which automatically triggers NEPA review to ensure that the proposed work is consistent with NEPA.

Safety Management Systems (SMS) and Safety Risk Management (SRM): Safety Management Systems (SMS) are an integrated collection of practices, procedures, and programs ensuring a formal approach to safety through risk management.[99] Safety Risk Management (SRM) is a formalized approach to safety. All oil and gas development projects must be implemented in accordance with the airport sponsor's SMS. The sponsor should notify the FAA Regional Office or ADO early in the process to determine the need or requirements for SRM. All construction proposed for well drilling, site development, and associated infrastructure must be submitted to the FAA in the form of a Construction Safety Phasing Plan (CSPP). The required content for the CSPP is available in AC 150/5370-2F, "Operational Safety on Airports During Construction," which includes the following elements:

- Emergency/Fire/Medical Response.
- Blowout Response.
- Storm water runoff management.
- Spill release response and containment of hazardous materials.
- Disposal and containment of hazardous materials.
- Compliance with federal, state, and local airport rules and regulations.
- Wildlife and uncovered ponds and waterways management.
- Airport areas and operations affected by the construction activity.
- Personnel and vehicle access.
- Foreign Objects Debris (FOD) management.
- Haul routes, roads, and excavation material storage and management.
- Notification of construction activities (Form 7460).
- Site monitoring, inspection, and enforcement responsibilities.

Form 7460, "Notice of Proposed Construction or Alteration": A sponsor proposing any type of construction or alteration of a structure that may affect the NAS is required to notify the FAA by completing the Notice of Proposed Construction or Alteration form (Form 7460). As part of the review, the FAA also evaluates the CSPP. A notice may be required for multiple phases of the project including exploration, devel-

[97]49 U.S.C. Section 47107(a)(9), "Hazard Mitigation (#20)."
[98]49 U.S.C. Section 47017(a)(16), "Airport Layout Plan (#29)."
[99]FAA, Order 5200.11, "Safety Management System (SMS)."

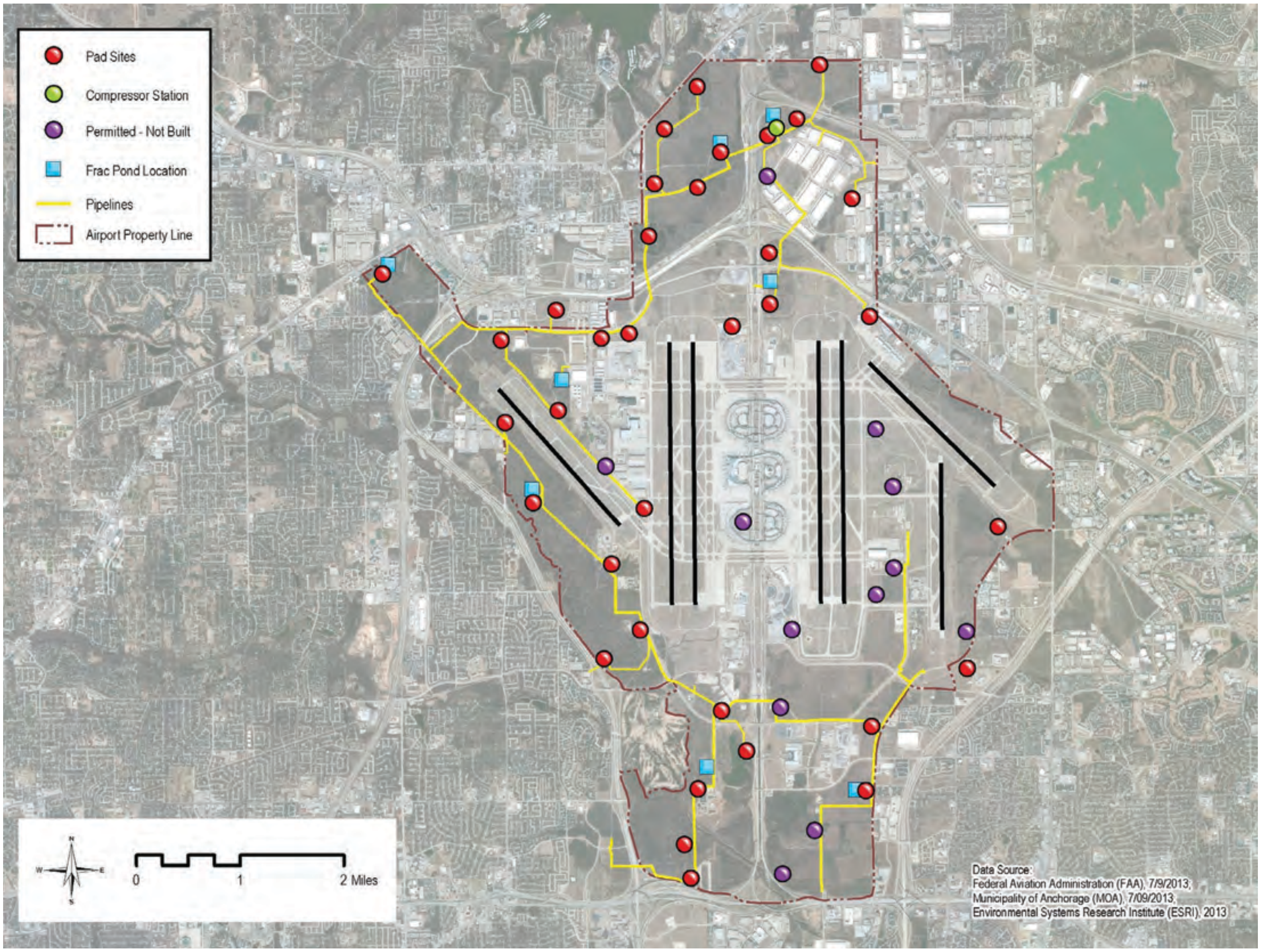


Figure 3.29. Oil and gas infrastructure at DFW Airport.

opment, and approval of the oil and gas production plan, construction at individual well sites, and well closure and reclamation.

3.3.4 Case Study: Dallas/Fort Worth International Airport (DFW)

Dallas/Fort Worth International Airport (DFW) is located in the Barnet Shale Play. It was approached by energy companies in the mid-2000s about opportunities to lease land for oil and gas development. With over 17,000 acres of land, DFW was a strong potential partner for oil and gas development. However, because such an extensive oil and gas development program had never been approved by the FAA, the airport and the FAA needed to work together along with Chesapeake Energy, the selected energy partner, to identify a leasing process and development network that could provide business success while protecting airspace and the environment. DFW also had its own approval process for which the drilling program would need to comply. This experience provides a useful model for future projects.

Figure 3.29 shows the network of oil and gas facilities that have been developed at DFW. The shale resource is located between 6,500 and 8,300 ft. below the land surface. Table 3.3 lists the elements of DFW's oil and gas development program by number of facilities.

Table 3.3. DFW's gas exploration infrastructure.

Facility	Number
Exploration Pad Sites	35
Frack Ponds	8
Active Wells	114
Planned Wells	300
Miles of Pipeline	35

The planning of the project started with the ALP. Airport zones were set up to organize the planning process. No exploration or development was allowed in the Air Operations Area (AOA), the most secure part of the airport. No pipelines were allowed to be located under runways or other critical aviation facilities. Seismic investigations by the energy company focused in on the areas of highest interest. Facility requirements were identified and based on planning guidance from DFW. Chesapeake Energy prepared a gas development plan. The closest pad to a runway is about 1,000 ft. Horizontal drilling allowed for extraction in areas closer to airport facilities, including the AOA. The distance of horizontal drilling is up to 1 mile. Figure 3.30 depicts a flight departing DFW over a gas pad in production.

Evaluation of potential airspace impacts was conducted based on planning zones. This included evaluation of physical penetration of the Part 77 imaginary surface as well as potential impacts on radars and ILS. DFW has two Air Surveillance Radar (ASR-9) sites on airport property that needed to be considered. It permitted a maximum structure height for each approved work zone. In evaluating the potential effect of the drill rig to the ASR-9, it was important to consider the angle of the rig to the radar. Chesapeake utilized the larger Nomac rigs where height was not an issue and the shorter Mountain rigs for areas closer to airport facilities. Rigs were required to be illuminated with yellow lights.

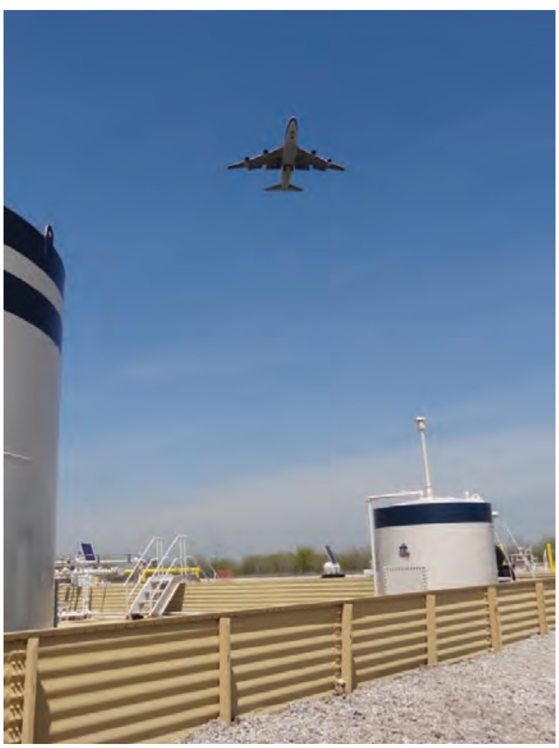


Figure 3.30. Aircraft departing DFW over gas pad in production.

Forms 7460 were filed for the planning zones with a maximum structure height (e.g., 177 ft.). FAA determinations stated no objection with conditions. The following is a list of conditions that were included in many of the determinations:

- A Form 7460 was filed for each individual structure proposed in the zone.
- Due to an identified effect on Instrument Flight Rules (IFR) for existing or any proposed instrument approach procedures, the sponsor must coordinate at least 72 hours in advance of the start of construction in the work zone with required mitigation (these are specific to one of the determinations):
  - RNAV GPS RWY 17R: Raise the LNAV/VNAV DA from 1000 to 1144; raise the LNAV MDA from 1000 to 1100. There would be no effect if the construction height were limited to 700 ft. above mean sea level (AMSL).
  - RNAV GPS RWY 17C: Raise the LNAV/VNAV DA from 1065 to 1144; raise the LNAV MDA from 1000 to 1100. There would be no effect if the construction height were limited to 700 ft. AMSL.
  - ILS or LOC RWY 17C: Raise the S-LOC 17C MDA from 1000 to 1060. There would be no effect if the construction height were limited to 700 ft. above AMSL.
  - RNAV GPS RWY 17R: Raise the LNAV/VNAV DA from 1000 to 1101; raise the LNAV MDA from 1000 to 1060. There would be no effect if the construction height were limited to 700 ft. AMSL.
  - RNAV GPS RWY 17C: Raise the LNAV/VNAV DA from 1065 to 1102; raise the LNAV MDA from 1000 to 1100. There would be no effect if the construction height were limited to 700 ft. AMSL.
- The Airport Sponsor is responsible for all local NOTAMs for work in and around the project area.
- The construction equipment associated with the project will be located very close to an FAA ASDE-X radar system, which is located approximately 2,400 ft., north-northeast from the proposed project site. The FAA National Field Support Office, ATO-W NASE, has conducted preliminary on-site modeling and simulation of a drill rig at the proposed site, using fire trucks with elevated ladder aerials. The results did not yield any adverse effects; however, the equipment used was approximately 1/20 the signature that an actual drill rig will present to the ASDE Radar System. Prior to erecting a drill rig at this site, the Sponsor shall coordinate with the FAA's D-10 Systems Operations Center (SOC) for coordination with the FAA Technical Operations Radar SSC organization, to have them actively monitor and assess the West ASDE systems' operation during the erection, including checking the initial full extended height configuration, and preparing the fully loaded drill rig pipe rack. This initial monitor and assessment period is expected

not to exceed more than 3 days. The sponsor may not start drilling operations until the initial ASDE operational monitoring and assessments have determined that no adverse operational effects have been observed from the drill rig.
- Given that construction equipment is proximate to Runways 17L, 17C, 18L, and 18R, construction equipment should be lowered close to the ground when not in use.
- The drill rig should be lighted with yellow fluorescent lights within the vertical channels of the drill rig and have a red light on top.
- The sponsor should ensure that light from the construction equipment should not interfere with air traffic or air operations.
- The sponsor should coordinate construction activity with the ATCT.
- All construction should be compliant with AC 150/5370-2E, Operational Safety on Airports during Construction.
- The project has a 1-watt communications monitor and control system and associated 43 ft. tall antenna for the gas well equipment that will remain. Prior to transmitting from this site, the sponsor shall coordinate with the FAA's D-10 SOC to ensure that there no adverse impacts on FAA systems.

The FAA dedicated staff resources to the airspace safety review to ensure that it was conducted in a comprehensive and efficient manner. DFW and FAA developed procedures to facilitate the reviews. Form 7460 packages were comprehensive when submitted. FAA completed its review in a 90-day period. About 99% of the notices were approved.[100] The most important standard was to have no long-term impact on the ILS. Impacts to ILS were limited to a 24 to 48 hour period. Some limited impacts on RNAV/RNP were considered acceptable. Short-term mitigation was employed by increasing the decision height.

DFW's approval process prohibits the flaring of the well as part of clean up. The Construction and Fire Prevention Standards Resolution and Amendments to the Codes updated in February 2011 under Part 9, Section 14 (n) states "Gas Emission or Burning Restricted. No person shall allow, cause or permit Gas to be vented into the atmosphere or to be burned by open flame except as provided by law or permitted by the Commission."

Eight frack ponds remain in place to support future drilling. Each is about 3 acres in area. Figure 3.31 shows an image of one of the ponds. The most significant concern from an airspace safety perspective is the ponds' potential impact as wildlife attractants. Thus, the ponds were designed to discourage wildlife by utilizing a block configuration, slippery liners, and

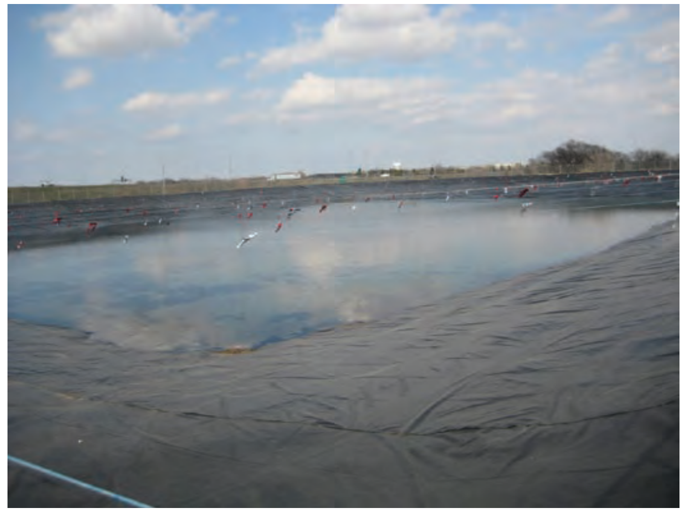


Figure 3.31. Frack pond at DFW with cross wires and flags to discourage waterfowl.

steep slopes. The pond could not include capability for draining, as the soils down-gradient are highly erodible. To discourage waterfowl from using the ponds, a network of wires spaced about 10 ft. apart was spread across the top of the ponds. Reports indicate that this system has been effective in keeping waterfowl out of the ponds. These ponds were approved in 2007. Future ponds may be required to be covered to better ensure against a wildlife hazard.

3.3.5 Lessons Learned

The development of oil and gas programs at several existing airports provides useful information for considering best practices and guidance. The flaring of wells has been a difficult impact to measure because the influence of flames and associated heat is variable and not well defined. Moreover, energy companies have alternative methods to achieve the same result. Referencing the case study example, DFW does not allow flaring, so the drilling company is required to either shut the well until regulator valves are installed or, if applicable, run the gas through pipeline connections from the lateral pipelines in to the main pipeline system.

Frack ponds are also a concern from a wildlife attractant perspective. At some airports, frack ponds have been constructed as temporary facilities to support the drilling operations and then returned to their pre-existing condition. In other cases, frack ponds have been retained as a facility to support future well development. Permanent facilities have been designed to include wildlife-discouraging attributes that may be useful for future projects, such as those at DFW.

The development and implementation of the DFW Oil and Gas Program also offers lessons in the level of coordination

[100]Barrett, S., Personal communication with Steven Tobey, DFW Manager of Airfield Operations, Harris Miller Miller & Hanson, Inc., February 4, 2013.

with the FAA necessary to efficiently review and determine potential impacts on airspace of a variety of temporary and permanent structures associated with drilling and how to successfully manage the impacts.

3.4 Power Plant Stacks and Cooling Towers

3.4.1 Research Context

Amid all of the new energy technologies being developed, traditional combined-cycle steam power electricity generation, fueled by an abundance of natural gas, continues to play an important role in the country's baseline energy network. According to the Federal Energy Regulatory Commission (FERC), 33% of all new electricity generation capacity constructed in 2012 was from natural gas-fired power plants (compared with 40% from wind and 17% from coal). Combined-cycle steam electricity generating plants are important because they produce electricity on demand (while wind produces when the wind blows and solar when the sun shines). In this respect, a more recent use of these facilities has been construction of smaller peaker plants, which are activated only when electricity demand spikes in summer and winter.

Other fuel sources of power plants include oil, coal, biomass, and CSP. Those that burn fossil fuels are equipped with stacks that release a heated exhaust. Some steam electricity generation plants also have cooling towers that release waste heat from fuel combustion into the atmosphere (see Figure 3.32). These facilities are large and often are reviewed for airspace impacts due to physical penetration. However, it is the non-physical penetration impacts associated with thermal and vapor plumes that have been of particular interest of aviation stakeholders. Thermal and vapor plumes can create a potential hazard to aircraft flying above the stack in the form of turbulent gusts which can cause potential upset of the aircraft. This section describes the potential impacts from power plant stacks and cooling towers on airports and aviation.

Figure 3.32. Cooling towers and vapor plume.

CRITICAL RESEARCH NEED—Power Plant Stack and Cooling Towers

Conduct a comprehensive review of the issues related to structure height and aviation safety impacts from thermal and vapor plumes to inform a consolidated set of guidance.

3.4.2 Characterizing Impacts

3.4.2.1 Overview

Whether from the stack or the cooling tower, the potential impacts occur when heated air rises from the power plant destabilizing the air environment and potentially disrupting aircraft. Smaller fixed-wing aircraft are particularly at risk due to their relative lightweight airframe, as turbulence could affect the control and maneuverability of aircraft. The exhaust gas is emitted from stacks as a result of the fuel combustion from natural gas, diesel oil, coal, or biomass used to power electrical turbines or steam generators. Gas turbine exhaust can reach up to 1,100°F for larger stations.[101]

Cooling towers produce thermal plumes when heated "cooling" water is exposed to ambient air and the waste heat is transferred to the ambient air and rises. Cooling tower plumes can also present visual impacts when the plume is saturated by moisture and the exhaust steam condenses with cooler ambient air similar to seeing one's breath on a cold winter day. The ability to see a plume depends on the type of release and weather conditions. The visible plumes could obscure the line-of-sight for pilots and ATC. In comparison to invisible vapor plume, the visibility of thermal plumes can be considered a benefit because potential turbulence can be seen and avoided (see Figure 3.33). Furthermore, plume abatement technologies using air to air heat exchangers to allow the mix of ambient air into the plume before it leaves the stack are available for cooling towers to limit the size and frequency of the visible plumes.

The exhaust temperatures and exit velocities for cooling tower plumes tend to be lower compared to the peaker and combined-cycle stacks. Even though cooling towers tend to have a less buoyant plume (due to lower temperatures and exit velocities), the stack diameters tend to be larger, which

[101] Environmental Protection Agency (EPA), "Technology Characterization: Gas Turbines," December 2008.

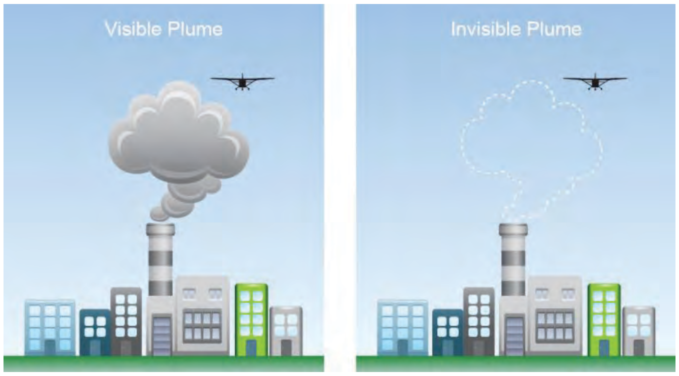


Figure 3.33. Visible vs. invisible plumes.

correlates to a larger mass flow and larger plume lateral dimensions. The larger lateral plume dimensions result in larger potential impact areas to aircraft when flying over a facility and their effects last longer when compared to the smaller diameter stacks with higher velocities where the potential duration is relatively small due to the smaller stack area.

Table 3.4 presents a comparison of exhaust parameters for a typical peaker plant, combined-cycle facility and a cooling tower. The peaker plant has the lowest stack diameter but the highest exit velocity and temperature compared to the combined-cycle and cooling tower sources. The cooling tower has the highest stack diameter but the lowest exit velocity and plume temperature.

3.4.2.2 Turbulence and Aircraft Upset

Exhaust plumes generated by the combustion of gases and discharge of waste heat have the potential to create in-flight hazards that affect the control and maneuverability of the aircraft. Under certain conditions, the plumes generated by the facilities can create turbulent conditions for aircraft that fly over or through plumes.

In reviewing FAA guidance in the AIM,[102] the FAA has developed turbulence intensity reporting criteria characterized in the following four categories:

1. **Light Turbulence:** Momentarily causes slight, erratic changes in altitude and or attitude (pitch, roll, and yaw).
2. **Moderate Turbulence:** Similar to light turbulence, but of greater intensity; changes in altitude and/or attitude occur but the aircraft remains in positive control at all times.
3. **Severe Turbulence:** Causes large, abrupt changes in altitude and/or attitude; usually causes large variation in indicated airspeed; aircraft may be momentarily out of control.
4. **Extreme Turbulence:** Aircraft is violently tossed about and is practically impossible to control; may cause structural damage.

NOAA has also developed vertical acceleration ranges in terms of G-force, or Gs on aircraft for each turbulence intensity category. G-force is technically not a force, but a measurement of acceleration felt as weight per unit mass. For flight, the G-force is typically experienced by the pilot on the body during sharp turns, acceleration, or combination of speed and direction. NOAA has defined the four categories of turbulence relative to the degree of sudden change in vertical acceleration of an aircraft, in terms of G-force:

1. **Light Turbulence:** 0.2 G to 0.5 G
2. **Extreme Turbulence:** Greater than 2 G
3. **Moderate Turbulence:** 0.5 G to 1 G
4. **Severe Turbulence:** 1 G to 2 G

The proximity of the plume and aircraft will also affect the potential impact. As illustrated in Figure 3.34, a plume contacting one side of the plane under the wing represents the maximum roll angle excursion, whereas a plume contacting the underbelly of the plane produces the maximum load factor change. The first example will cause an abrupt lateral imbalance in flight. The second will cause the entire plane to experience a dramatic change in lift. Where the plume is invisible, the pilot may experience larger pitch or bank excursions because of the unexpected nature of the plume's effects.

3.4.2.3 Flight Tests

Several flight tests have been conducted to assess aircraft handling characteristics and responses when penetrating a convective thermal plume emanating from a power plant. One test was conducted in November 2010 at the Calpine Sutter Power Plant in Sutter County, California.[103] Nine passes were conducted between 500 and 1,000 ft. above the power plant stack. The pilot concluded that no turbulence was detectable at 1,000 ft. At 750 ft., the turbulence was characterized as a "slight burble." At 500 ft., a very slight aircraft upset was experienced requiring only minor flight control inputs to maintain level flight. The observer determined that the upset for pitch and roll axis never exceeded 7 degrees. A slight altitude increase and rate of climb were also experienced. The observers concluded that the power plant plume did not represent a significant threat to GA aircraft operating at traffic pattern altitudes.

[102]FAA, *Aeronautical Information Manual (AIM)*, "Turbulence Reporting Criteria," Table 7-1-10: http://www.faa.gov/air_traffic/publications/ATpubs/AIM/aim0701.html#aim0701.html.49.

[103]Wardell, D. and D. Moss, "Joint Flight Test: Aircraft Handling Characteristics During Convection Plume Penetration," Calpine Sutter Power Plant, California, 2010.

Table 3.4. Comparison of different stack and exhaust properties.

Facility	Type	Stack Diameter (ft.)	Exit Velocity (fps)	Temperature °F
Eastshore Energy Center	Peaker Plant	3.96	76.9	713
Blythe Energy Project Phase II	Combined Cycle	21.5	39	252
Blythe Energy Project Phase II	Cooling Tower	30	31.4	57

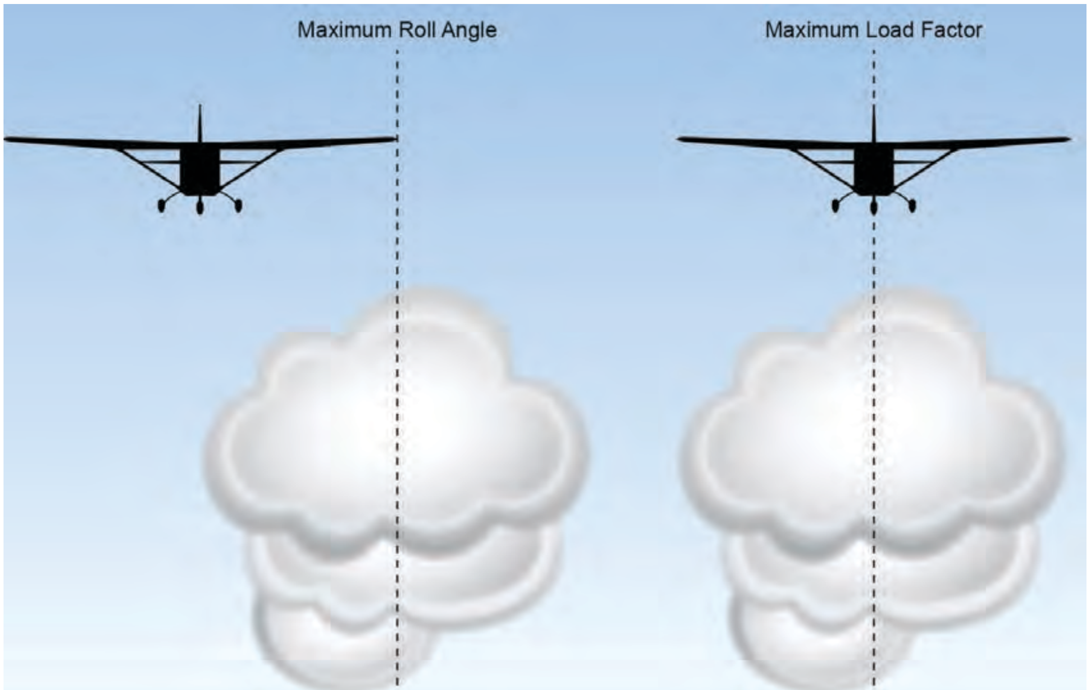


Figure 3.34. Variance of turbulence impact on aircraft dependent on position relative to plume.

A second test was conducted at the Indigo Energy Facility near Palm Springs, California.[104] This test included two planes, one equipped with a Data Acquisition System and the second with the ability to collect photographic documentation. Data were collected for cruising configurations that would be expected in this area. The height of flights was dictated by the height of existing nearby structures, which were utility-scale wind turbines. All flight traffic must stay a minimum of 500 ft. above the wind turbines. When the aircraft entered the plume, the typical response was an abrupt but minor change in pitch, angle of attack, and occasionally bank angle when the plume interacted with just one wing. In all cases, the aircraft stabilized on its own within 1 second of exiting the plume. Consequently, the pilots had no difficulty maintaining control of their aircraft.

In a third study, two flight tests were flown through the thermal plume of the Walter E. Higgins Power Plant near Primm, Nevada.[105] The data collection was similar to that collected at the Indigo Energy Facility, but included both cruise and landing configurations. A variety of heights above the stack were flown, although data collection was focused on 500 ft. above the facility's Air-Cooled Condenser (ACC). The aircraft response to the plumes varied from high-frequency/low-amplitude aerodynamic chop to oscillatory bank angle changes of up to 25 degrees of bank. The variations generally were more prominent when the aircraft was closer in altitude to the source of plume. Since the ACC was adjacent to the Heat Recovery Steam Generators (HRSG), some of the aircraft responses were likely due to the HRSG plume as opposed to the ACC plume. For those points where the ACC was the contributor, the aircraft response was more benign. Even at 500 ft. above the facility, the aircraft was fully controllable and recovery from any dynamic upset was fully within the capability of a student pilot with limited experience.

[104] Moss, D., "Flight Test Report: Aircraft Handling Characteristics during Convection Plume Penetration of Indigo Energy Facility, California," 2010.

[105] Moss, D., "Flight Test Report: Glint/Glitter Evaluation of SEGS and Convection Plume Evaluation of Walter Higgins Power Plant, California," 2010.

3.4.2.4 Modeling Potential Impacts—MITRE Study

There have been numerous studies conducted by consultants and government agencies to evaluate exhaust plumes and the potential hazard to aircraft. Recently, MITRE released its long awaited study for FAA on the effects of vertical plumes on aviation.[106] The study included the development of a Plume Hazard Model to evaluate potential plume behavior from an exhaust stack along with the potential impact the plume could have on aircraft performance when flying over or near the exhaust stack.

The MITRE study is a follow-up to the FAA's "Safety Risk Analysis of Aircraft Overflight of Industrial Exhaust Plumes" (January 2006), which examined 671,000 pilot reports over 30 years, along with more than 150,000 accident and incident reports from the FAA National Aviation Safety Data Analysis Center (NASDAC) Accident/Incident Data System (AIDS). The purpose of the study was to evaluate the potential safety risk hazards associated with the following:

- Plumes that could result in possible airframe damage and/or possible effects on the aircraft stability.
- The effects of high water vapor plumes, engine/aircraft contaminants, icing, and restricted visibilities produced by these plumes.

The safety risk study findings indicated that the risk of an accident from an over flight of a small plane was low; however, the report did note that there is the potential for aircraft upset to occur when flying in the immediate vicinity of the exhaust plume.

As a follow up to the FAA's "Safety Risk Analysis," MITRE developed the Plume Hazard Model to predict the potential effects of thermal plumes on aircraft. The model has the ability to evaluate plume rise and plume characteristics from an exhaust stack while also incorporating turbulence and aircraft response models to evaluate the degree of turbulence that could be expected above the exhaust stack and its effect on different aircraft types. The plume model allows a user to model the exhaust stack(s) to evaluate the area to avoid around the plume during certain weather conditions. The model can also estimate elevated temperatures and oxygen content of the plume above a stack, which can be used to assess potential hazards to helicopters. The MITRE report found that there was a definite risk of light aircraft experiencing severe turbulence within the target level of safety (TLS) as they fly over an exhaust plume during certain weather conditions. The report did find that it was unlikely that an aircraft would reach upset criteria, or a condition that causes the aircraft to pitch or bank at certain angles causing the aircraft to lose control.

The MITRE study was conducted in response to pilot concerns of thermal plumes and their potential to create turbulent conditions for aircraft and the increasing aviation incidents involving plumes both in the United States and internationally. There are numerous examples, especially in California, of aircraft affected by power plant plumes during take-off and/or landing at airports.[107] The Oregon Pilots Association is currently commenting actively on the potential thermal plumes and visual impacts from cooling towers with the siting of two proposed power plants near the North Bend and Troutdale airports in Oregon.[108] The MITRE study builds upon the FAA "Safety Risk Analysis" and guidance from the Australian Civil Aviation Safety Authority (CASA) (see Section 3.4.3.1) to develop a unique modeling tool to evaluate plume characteristics and dispersion once they leave the stack and to address the potential impact to aircraft.

The Plume Hazard Model is composed of several component models. One model evaluates the plume velocity after it leaves the stack. Two other models incorporate aircraft response to predict the effect of the plume on three different types of aircraft. The model is run via a graphical user interface (GUI) where the user can input stack parameters, including single and merged stacks, meteorological conditions, gust percentile, and aircraft type. Three aircraft type are available within the model for evaluation ranging in size and weight—North American Navion, a Lockheed Jetstar business jet, and a Convair CV-880M jet. The model will produce the "Maximum Vertical Acceleration" plot, which shows areas above the exhaust stack where light, moderate, severe, and extreme turbulence could be experienced for different size aircraft based on the user inputs. This can help a pilot identify the area of potential severe turbulence and avoid such region around the exhaust stack. Some important information from the study on plume dispersion and its effect on aircraft was as follows:

- Creating a dispersion model to establish the plume velocity and temperature after the plume leaves the stack based on meteorological data and exhaust stack parameters.
- Ability to account for multiple stacks which can cause merged plumes and enhance buoyancy.
- Turbulence model to account for the velocity fluctuations or turbulent gusts of the plume over time.
- Aircraft Response Model to determine the effect the plume has on an aircraft flying over it.

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[106]FAA, "Expanded Model for Determining the Effects of Vertical Plumes on Aviation Safety," September 2012.

[107]DeVita, P., Personal Communication with C. Ford, Harris Miller Miller & Hanson Inc., 2010.

[108]DeVita, P., Personal Communication with M. Rosenblum, Harris Miller Miller & Hanson Inc., 2012.

- Establish Turbulence categories and vertical acceleration and turbulence intensity for the plume velocity and potential impact to aircraft.
- Establish upset criteria to determine if aircraft upset could occur.
- Probability of Risk of how often the event could occur.
- Helicopter Risk to establish a threshold for maximum temperatures and oxygen content of the plume.

3.4.2.5 Other Characterization Tools

Modeling is also used to evaluate impacts from cooling towers, most notably the Seasonal Annual Cooling Tower Impact (SACTI) model. The SACTI model was developed by Argonne National Laboratory and University of Illinois in the 1980s and provides seasonal and annual impacts from cooling towers. The model is capable of predicting frequency (including lengths and heights) of visible cooling tower moisture plumes along with the potential hours of fogging and icing. Currently, FAA has no standards for regulating visual impacts from thermal plumes.

3.4.3 Managing Plume Impacts

While there are several sophisticated modeling tools available for predicting the characteristics of a plume and potential influence on aircraft, there are no specific federal U.S. standards or guidelines to evaluate if the impact is significant. However, guidelines developed in Australia and general FAA guidance offer some strategies for managing potential plume impacts and minimizing impact.

3.4.3.1 Australia CASA Plume Velocity Criterion

In response to a proposal to construct a simple cycle gas turbine at the end of a runway in the early 1990s, Australia's CASA began evaluating potential impacts of new exhaust stacks near airports. CASA was concerned that the vertical velocities from the exhaust have the "potential to damage and/or affect the handling characteristics of an aircraft in flight." To address thermal plume impacts, the CASA issued an AC in June of 2004 to develop guidelines for conducting plume rise assessments for exhaust plumes that trigger significance criterion.[109] The guidance established that "exhaust plumes with a vertical gust in excess of the 4.3 meters per second (m/s) threshold may cause damage to an aircraft airframe, or upset an aircraft when flying at low levels." Typical low-level operations consist of approach, landing, take-off, search and rescue, and low-level military maneuvers. The origin of this threshold is unknown and CASA was unable to verify the source of the threshold.[110] However, CASA had used the 4.3 m/s as a significance criterion on past power projects prior to issuing the AC.

The 4.3 m/s is not a standard, but rather a trigger for further plume assessment in order to evaluate the potential hazard to aircraft operations. The CASA assessment takes into account the location of the plume relative to the airport and active airspace, stack exhaust parameters, and local meteorology. The plume assessment consists of a screening and a more refined approach. The screening approach assumes calm wind conditions, which are conservative, resulting in worst case conditions. The guidance provides for a more refined plume assessment to include local meteorology and complex numerical modeling of the thermal plume. Using the local meteorology allows for the determination of the frequency distribution of the plume at the critical height (i.e., the height of the plume where the plume velocity is 4.3 m/s or greater) over a year of meteorological conditions. The frequency distribution of the thermal plumes at the critical height is used to evaluate if there could be a potential hazard to aircraft safety and how often the conditions could exist over the year. The guidance is not limited to single stacks, but also includes a methodology for analyzing the impact from multiple stacks and merged plumes. Multiple exhaust stacks located near each other could have individual plumes that merge and form a higher buoyancy combined plume, which could enhance the vertical velocities of the plume and enhance the gust of the plume or turbulence. If the plume assessment identified a potential hazard, the original guidance generally managed any potential risks by directing pilots to avoid flying over the exhaust stack.

The CASA guidance was recently updated in 2012 to include a new critical plume velocity criterion of 10.6 m/s along with a revised plume assessment methodology and new mitigation options if the plume assessment shows a potential hazard to aircraft. The new 10.6 m/s criteria is based on Airservices Australia's "Manual of Aviation Meteorology"[111] and defines severe turbulence as vertical wind gusts in excess of 10.6 m/s which may cause a momentary "loss of control." The new AC provides criteria to determine when CASA may take action during IFR and VFR conditions. However, these are not explicitly defined thresholds and CASA may include other factors similar to the original guidance, such as the height at which the aircraft may fly over the exhaust plume and probability of occurrence. The plume assessment methodology under the new guidance is similar to the old guidance but has standardized the methodology to allow for consistent

[109] Australia Civil Aviation Safety Authority (CASA), "Guidelines for Conducting Plume Rise Assessments," AC 139-05(1), November 2012.

[110] DeVita, P., Email to Anna Henry, CASA Airspace Specialist, Harris Miller Miller & Hanson Inc., June 5, 2013.

[111] Airservices Australia, "The Manual of Aviation Meteorology," 2003.

and reliable review of the plume assessment using computer-based modeling. The assessment should evaluate the height at which the plume velocity from the exhaust stack reaches the average vertical velocity criterion of 4.3 m/s along with the new critical plume velocity criterion of 10.6 m/s. To put these two thresholds into some perspective, the 4.3 m/s is equivalent to the wind blowing at 9.61 mph (or 8.4 knots) and the 10.6 m/s threshold is equivalent to a wind blowing at 23.7 mph (or 20.6 knots). Using the Beaufort Wind Scale,[112] the 4.3 m/s is characterized under the Beaufort scale as a gentle breeze described as leaves and small twigs constantly moving. The 10.6 m/s is characterized as a fresh breeze described where small trees in leaf begin to sway. The CASA guidance provides new mitigation options, such as inserting a symbol and height on aviation charts to denote awareness of the plume rise, designation of a danger area on aviation charts to alert pilots to the plume hazard, or designation of a restricted area on the chart to alert pilots not to fly over the area. It also denotes that CASA may recommend against the development of the project if mitigation cannot be implemented.

Absent other available review criteria, regulatory agencies outside of Australia have used the CASA guidance in evaluating potential impacts. The California Energy Commission (CEC) has applied the CASA 4.3 m/s threshold to new power plant applications in considering potential thermal plume impacts to aircraft. For the proposed Blythe Solar Power Plant, the CEC decision required that air nautical charts be updated to reflect the potential hazard. For the Ivanpah Solar Power Plant, the CEC decision restricted aircraft to flying no lower than 1,350 ft. over the facility.

3.4.3.2 MITRE Study Guidance

Since severe turbulence can cause large and abrupt changes in altitude and/or attitude, thereby causing the pilot to temporarily lose control of the aircraft, a MITRE study concluded that the potential to create more than a 1G vertical acceleration from the plume velocity on an aircraft was established as a safety threshold. Potential gusts from plume exhaust that could cause a peak vertical acceleration of greater than 1G should be avoided.

The study also looked at the aircraft upset standards and upset criteria based on the FAA's Airplane Upset Recovery Training Aid.[113] While there were many conditions that could cause aircraft upset including pitch attitude and inappropriate airspeeds, the study focused on the bank angle upset condition in the roll response model as the criterion for assessing aircraft upset from the plume gusts and was incorporated into the Plume Hazard Model. As the pitch of the aircraft increases, the potential increases for aircraft upset conditions to occur. In the case of thermal plumes, the potential for turbulence on the aircraft from the plume could cause the aircraft to increase its bank angle and cause an upset condition in flight. Using the FAA criteria and the roll response model, the study considered as a significance criteria that an aircraft upset condition could occur if the bank angle exceeds 45 degrees.

The study included the TLS of 1.0×10^{-7} that was considered the acceptable level of risk based on the 2006 FAA Safety Risk Analysis and was based on the ATO SMS Manual[114] qualitative criteria for risk. To put this into perspective, there are five likelihood definitions in the ATO Manual ranging from "frequent" to "extremely improbable," with corresponding probability of occurrences ranging from 1×10^{-3} for "frequent" occurrences to 1.0×10^{-9} for "extremely improbable" occurrences. The TLS was determined to be one chance in 10 million of a fatal accident occurring. The study found that the accident or incident rate of overflights of exhaust plumes was determined to be one chance in 1 billion or less. The 1.0×10^{-7} TLS used in the MITRE and FAA Safety Risk Analysis represents a remote likelihood of an event equivalent to an occurrence once every year. The TLS was based on historical data and gust amplitude. The study highlights that the TLS of 1×10^{-7} risk level is very small. However, the MITRE report did note that while the risk was lower than the TLS for an aircraft accident caused by the plume, it did denote that there was potential for aircraft upset to occur when flying over the immediate vicinity of the plume.

3.4.3.3 FAA Guidance to Pilots

The FAA under the TERPS requires that approach procedures are designed to maintain certain vertical margins between fixed objects (e.g., exhaust stacks) and aircraft by 1,000 ft. within the initial approach fix, 500 ft. within the intermediate fix, and 250 ft. within the final approach. The AIM was updated in 2010 at the request of numerous stakeholders (e.g., Aircraft Owners and Pilots Association [AOPA]) to include visible and invisible plumes and highlight their potential effect on aircraft and pilots. AIM Chapter 7-5-15 was updated to include a warning to pilots to avoid flight near thermal plumes including smoke stacks and cooling towers.

A NOTAM is typically issued by a government agency to alert pilots to potential hazards along the flight route or at a specific location that could affect the safety of the aircraft. The FAA issued a NOTAM on October 8, 2004, which states as follows: "In the interest of national security, and to the

[112]U.S. National Oceanic and Atmospheric Administration (NOAA), "Beaufort Wind Scale": http://www.spc.noaa.gov/faq/tornado/beaufort.html.

[113]FAA, "Airplane Upset Recovery Training Aid, Revision 2," 2008: http://www.faa.gov/other_visit/aviation_industry/airline_operators/training/media/AP_UpsetRecovery_Book.pdf.

[114]FAA, "Air Traffic Organization: Safety Management System Manual, Version 2.1," 2008.

extent practicable, pilots are strongly advised to avoid the airspace above, or in the proximity to such sites as power plants (nuclear power plants, hydroelectric, or coal); dams; refineries; industrial complexes; military facilities; and other similar facilities."[115] This NOTAM was intended to protect power plants from potential security breaches by piloted aircraft, in response to the September 11, 2001, terrorist attacks. Still, this guidance represents an operating restriction to aircraft in relation to energy facilities and, therefore, bears mentioning.

3.4.4 Helicopters

The potential impacts on helicopters from plumes represent a separate case, which was also considered in the MITRE study. For helicopters, the hazards are not necessarily from the turbulence created by the plume but from the high temperatures and low oxygen content of the plume. Helicopters have maximum operating temperatures and minimum oxygen content required for safe operation. Elevated temperatures and/or low oxygen content can cause the engines to fail. These conditions are significant concerns around exhaust stacks, especially from flares burning flammable gases from pressure relief valves near gas wells and offshore oilrigs (see Section 3.3).

Based on a review of a variety of helicopter specifications, the MITRE study established a maximum operating temperature threshold of 52°C. Plume temperatures above 52°C were considered unsafe for helicopter operations. The Plume Hazard Model has the ability to estimate the plume temperature with height, allowing helicopter operators to evaluate not only the turbulence area but also the temperature of the plume and assess the relative safety levels above the stack. In addition to the plume temperature, the oxygen concentration of the plume can also be estimated. Using the FAA report on jet fuel, it was found that 12 percent oxygen is required to ignite the fuel at altitudes below 10,000 ft. The 12 percent oxygen threshold was considered the minimum oxygen threshold requirement for the study and one of the variables used in the model. By assuming a worst case scenario of 0% oxygen plume content from the stack, and a typical value of 20.9 percent oxygen content in the air, the areas of reduced oxygen above the stack can be estimated in the model and compared to the 12 percent minimum oxygen criteria identified by FAA (see Figure 3.35).

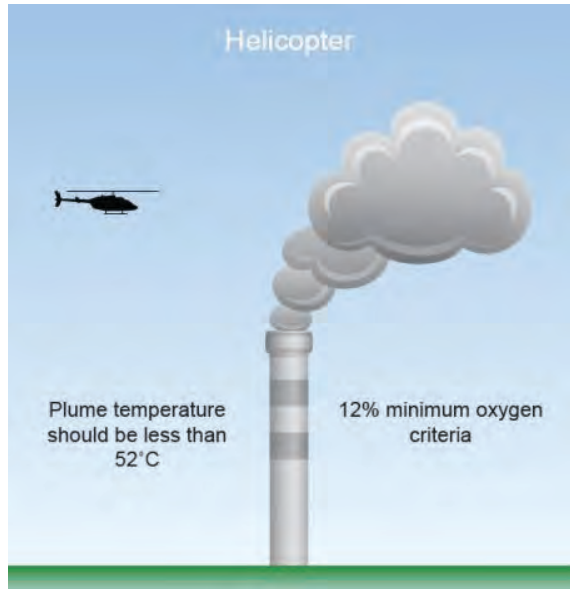

Figure 3.35. Criteria for helicopter flight near plumes.

3.4.5 Case Study: Eastshore Energy Center

The Eastshore Energy Center was a proposed 115.5 MW peaking power plant located in the city of Hayward, California, approximately 1 mile from the Hayward Executive Airport. The proposed plant consisted of 14 natural gas-fired engines each with a 70-ft. exhaust stack. There were numerous concerns about the facility including air quality, noise, public health, global warming, property values, and aviation safety. The CEC evaluated the project for years and eventually denied the application to build the facility based on deficiency in five areas,[116] including the following related to aviation:

- The facility would cause a significant cumulative public safety impact on the operations of the nearby Hayward Executive Airport by further reducing already constrained air space and increasing pilot cockpit workload.
- The thermal plumes from the facility would present a significant public safety risk to low flying aircraft during landing and take-off maneuvers because of the close proximity of the Hayward Airport.
- The facility would be inconsistent with the city of Hayward's Airport Approach Zoning Regulations and incompatible with the Alameda County Airport Land Use Policy Plan.

It should be noted that the FAA issued a No Hazard Determination for the 14 stacks on May 15, 2007, and the CEC still rejected the project for the reasons stated above. The nearby Russell Energy Center, also in Hayward, is a proposed 619 MW power project located approximately 1.5 miles from

[115]FAA, Notice to Airmen (NOTAM), FDC 4/0811.

[116]California Energy Commission (CEC), "Final Decision: Eastshore Energy Center," Sacramento, 2008: http://www.energy.ca.gov/2008publications/CEC-800-2008-004/CEC-800-2008-004-CMF.PDF

Hayward Executive Airport. The two 145-ft. exhaust stacks were evaluated by the FAA and a No Hazard Determination was issued for the project. The CEC evaluated the proposed Russell Energy Center and approved the project's Application for Certification. The Russell Energy Center commenced operation in August of 2013.

3.4.6 Lessons Learned

The issue of thermal plume impacts on small fixed-wing aircraft and helicopters represents another example of a non-physical intrusion of airspace that is difficult to measure and therefore difficult to establish significance criteria. As stated in the MITRE report conclusion section, "while it is unlikely that an aircraft will reach upset criteria, there is a definite risk of light aircraft experiencing severe turbulence within the TLS as they fly above an exhaust plume emitted from a power plant or other industrial facility in certain weather conditions." There are numerous documented incidents of pilots reporting turbulence when flying over exhaust stacks. However, no specific regulatory criteria have been developed due to the difficulty of characterizing impacts. Australia's CASA identified the need for plume hazard evaluations and developed a methodology through an Advisory Circular in 2004, which was recently updated in 2012 to account for new criterion to address "severe turbulence" and "loss of control" to an aircraft. Since the CASA guidance is the only formal regulatory criteria in use, it will likely be used by other regulatory bodies when evaluating potential effects. As power plants are large structures visible in the landscape, the clearest guidance is to avoid flying over power plants especially when flying at low altitudes and be aware of potential turbulence in the area from exhaust stacks as this turbulence can be either visible or not visible depending on weather conditions.

3.5 Electricity Transmission Infrastructure

3.5.1 Research Context

Electricity transmission infrastructure, which is composed of transmission towers, electrical lines, and associated facilities, represents one of the largest interconnected structures in the world. High voltage transmission (230 kilovolts and greater) covers more than 200,000 miles in the United States.[117] As new energy generation sources like renewables are developed far from population centers, new transmission lines are required to deliver the electricity to users. Transmission lines crossing more remote locations can present new impacts to local populations including potential effects on airspace safety.

> **CRITICAL RESEARCH NEED—Electricity Transmission Infrastructure**
>
> Identify new transmission projects and collect information to assess if the projects have affected airspace, in addition to collecting more information on the aviation safety impacts from existing electricity infrastructure.

Electricity transmission impacts on aviation are primarily related to physical impacts. Since transmission lines are an essential component of delivering energy to consumers, they are ubiquitous throughout the landscape. The degree of potential impact is correlated with the amount of power being delivered and the size of the infrastructure. Large transmission towers that are several hundred feet tall are necessary to hold up large high voltage transmission lines. These large structures are comparatively closer to the energy generation facility. Advancements in transmission technology are creating more efficient delivery with less power loss over long distances (i.e., line losses) making long-distance transmission more economical. The utility poles and power lines decrease in size as power is delivered to businesses and people. It is more common for the public to request that transmission lines be buried for aesthetic reasons though utilities usually try to avoid burial except where necessary due to the increased cost of doing so.

Existing power lines are common obstructions near airports. Many of these lines are either long-lived, were upgraded over time without input from airport and aviation stakeholders, or have become obstructions as airports have expanded. It is also likely that utility poles adjacent to remote airports have not been appropriately inventoried as potential obstructions.[118]

3.5.2 Characterizing Impacts

3.5.2.1 Physical Obstructions

Electric transmission lines and the towers that support them can rise high enough to impact airspace. The transmission towers that support the electrical lines are the tallest part of the facility. The towers are typically constructed of a lattice steel

[117] Edison Electric Institute, "Transmission": http://www.eei.org/issuesandpolicy/transmission/Pages/default.aspx

[118] Barrett, S., Personal Communication with Robert Knowles, Renewable Energy Massachusetts, about a proposed solar project near Fitchburg Airport (Massachusetts), Harris Miller Miller & Hanson Inc., July 10, 2013.

frame and average between 50 and 180 ft. tall depending on the size of the electrical line being carried among other factors.[119] However, transmission towers exist that are as tall as 1,100 ft.[120]

During the project review process, if the FAA is sufficiently notified, it may comment on potential effects of a proposed power line project and request consideration of alternatives to avoid a potential impact. Alternatives might include a different route for the transmission line away from airspace receptors, lower structures, or burying the power lines underground. If none of these options is feasible, the FAA could determine that the project is not an airspace hazard if appropriate lighting and marking is included, or it could determine that it is a hazard and consider potential modifications to approach procedures. It is customary that transmission infrastructure near airports has lighting and/or marking. The FAA's AC 70/7460-1K, "Obstruction Marking and Lighting," provides guidance on the types of lighting and markers that meet FAA requirements.

3.5.2.2 Communications Systems Interference

Communications systems interference results when a structure produces a physical or electrical barrier to communications facilities. Such facilities associated with the NAS include radars, ILS, and NAVAIDs. Electric utility infrastructure can produce electromagnetic interference (EMI). Devices employing solid-state switching can place high levels of impulse current and voltage onto the electric wiring, ground conductors, and other metal components associated with a source. These impulses pass through the transformer and onto the conductors of an overhead distribution line providing electric power to the facility. Interference radiating from the building conductors and the overhead power line conductors of a distribution line associated with such a facility can result in interference to radars located within line-of-sight of the overhead lines. In addition, corona interference can occur from transmission lines operating at high voltages (typically from 69 to 750 kV, and in some special cases up to 1 MV). A corona can develop as the breakdown of air at very small and sharp metal protrusions that form on a power line or switching substation. When these small protrusions are removed, the corona noise will disappear.

As described in "Procedures for Handling Airspace Matters," the FAA is "authorized to establish, operate, and maintain air navigation and communications facilities and to protect such facilities from interference. During evaluation of structures, factors that may adversely affect any portion or component of the NAS must be considered. Since an EMI potential may create adverse effects as serious as those caused by a physical penetration of the airspace by a structure, those effects must be identified and stated." (The procedures include some specific guidelines for power lines, which are outlined in Table 4.5.)

3.5.3 Managing Impacts

Many transmission line projects proposed near airports have filed Form 7460, which triggers aeronautical studies by the FAA to ensure that impacts to airspace are avoided. However, the project proponent may not always be aware of the need to file with the FAA. Projects subject to NEPA review, or similar state environmental reviews, will include a process whereby potential effects on transportation systems must be assessed and the FAA and local airports will be consulted. In other cases, the airport may become aware of a proposed project and request that the applicant consult with the FAA about potential impacts. Project experience offers the best information on how the impacts of transmission lines can be managed.

There have been recent reports of large transmission lines that have been constructed without obtaining FAA approval. A post-construction analysis of airspace impacts conducted by the FAA may determine that the project presents a hazard to air navigation. In such instances, the FAA has three potential options: (1) require the dismantling to the violating section of line, (2) place lighting and other facilities on the line, and (3) change the approach minimums.

A 12.9 mile, $21 million 115-kV power line project was constructed in November 2010, which runs as close as ½ mile northwest of the runway at Blake Municipal Airport in Delta, Colorado. It was determined that the engineers miscalculated the latitude and longitude they inserted into the FAA's "Notice Criteria Tool," an online program that proponents can use to assess if their project may be subject to FAA review. The transmission company had obtained a county permit that was conditioned upon receiving all federal and state approvals. The FAA completed its aeronautical study after the fact and determined that the power lines represent an air navigation hazard, though it has no authority to require that the lines be moved. Only the Delta County Commission can exercise that right. The power company agreed to lower the lines to minimize impacts.

Power lines can also present obstacles to airport expansion projects. The extension of the DeKalb County (Georgia) Airport's runway to 7,000 ft. required the burial of existing power lines to avoid an airspace obstruction. The cost of burial in this case was approximately $1 million, paid for by the FAA as part of the expansion project. Additionally, power lines are

[119]International Finance Corporation (IFC), "Environmental Health and Safety Guidelines for Electric Power Transmission and Distribution," April 30, 2007: http://www.ifc.org/ifcext/enviro.nsf/AttachmentsByTitle/gui_EHSGuidelines2007_ElectricTransmission/$FILE/Final+-+Electric+Transmission+and+Distribution.pdf.

[120]One such tower is produced by Alimak Hek: http://alimakhek.com/.

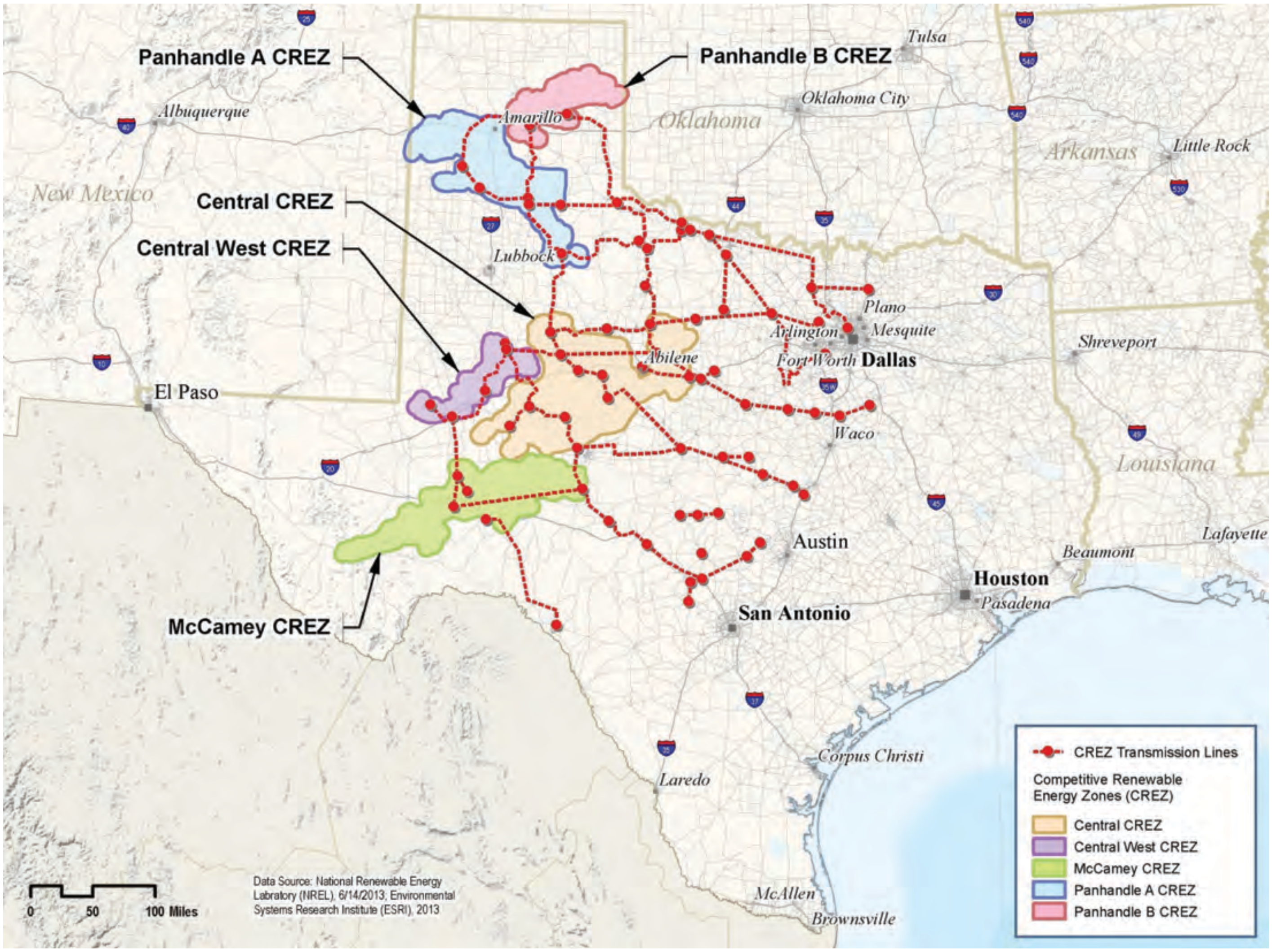

Figure 3.36. Location of Competitive Renewable Energy Zones (CREZ) in Texas.

listed as an obstruction to Runway 36 at Waterbury-Oxford Airport in Connecticut.[121]

3.5.4 Airspace Case Study: Texas Competitive Renewable Energy Zones (CREZ)

The Electric Reliability Council of Texas (ERCOT), established in 1975 to oversee the electric and telecommunications industries in Texas, was directed by legislation passed in 2005 to develop Competitive Renewable Energy Zones (CREZ) in the state. A CREZ is a geographic area with optimal conditions for the economic development of wind power generation facilities. Five CREZ areas were established and specific transmission projects were identified that would deliver 18,500 MW of wind power from west and north Texas to the more densely populated parts of the state. Figure 3.36 shows the location of the CREZ areas relative to population centers in Texas.

As part of this project, the Central CREZ was visited. There has already been a high density of wind power development in the area including the Horse Hollow wind project, which is referred to as the largest wind farm in the world (see Figure 3.37). This high plains area southwest of Abilene was viewed in the field from U.S. Route 277 and State Route 153. According to the American Wind Energy Association, there are 1,863 wind turbines in this area.[122]

New transmission infrastructure that has been constructed as part of the CREZ project was also identified in the field. The Scurry Transmission Project, shown in Figure 3.38, includes

[121] Aircraft Owners and Pilots Association (AOPA), Airports listing for Waterbury-Oxford Airport: http://www.aopa.org/airports/KOXC.

[122] As researched on the AWEA website, accessed August 30, 2013: http://www.awea.org

Figure 3.37. Horse Hollow wind farm southwest of Abilene.

Figure 3.38. Recently constructed transmission lines as part of the CREZ project.

these transmission lines identified perpendicular to State Route 70 just north and west of Sweetwater, Texas.

After the site visit, airports were contacted in the area between Sweetwater and Lubbock, where the recently constructed transmission line was located. Seven airports were identified. Three of the airports were determined as no longer operational based on satellite imagery and of the four remaining, two had non-operational telephone numbers. The remaining two were contacted and staff at Hamlin Municipal Airport (14F) in Hamlin and Avenger Field Airport (SWW) in Sweetwater both stated that they were not aware of any airspace problems associated with the new transmission lines.

3.5.5 Lessons Learned

The topic of transmission line development and airspace impact illustrates a few key points. First, as transmission lines have been constructed in the same manner for over 100 years (i.e., power lines attached to utility poles), many such obstructions exist near airports. Aircraft are alerted to these obstructions when reviewing information and procedures for specific airports and some areas are being mitigated over time. A variety of mitigation options are available to address existing problem sites, including making physical modifications (e.g., lowering the height or burying the lines), placing lights or signal ball markers, or increasing minimum altitude standards.

In addition, some transmission projects may not be reviewed by the FAA or aviation stakeholders, so those obstructions may not be identified until project construction occurs and impacts are observed. This suggests how important it is that airports and local stakeholders maintain awareness of electricity transmission development projects in the area of airports and that they refer any potential issues to the FAA's Regional Office or ADO.

CHAPTER 4

Guidance

The development of new domestic energy sources to support economic development and national security will result in potential safety impacts on the U.S. air transportation system. Aviation and energy stakeholders alike will benefit from development of best practices to address these impacts. The objectives of this Guidebook are to (1) deliver an overview of the National Airspace System (NAS) and how aviation safety is regulated in the context of energy technology development, (2) give a detailed account of research and lessons learned related to the aviation safety impacts of certain energy technologies, and (3) establish best practices for planning and implementing energy production and transmission technologies for preservation and improvement of aviation safety.

Chapters 2 and 3 provide significant technical depth regarding airspace and airport operations, aviation regulations, energy technology development near airports and other NAS resources, and related safety implications. This chapter, in contrast, is intended to be an accessible guidance resource for best practices related to each energy technology covered previously. Please refer to Chapters 2 and 3 for more detail related to these best practices.

The guidance provided in this chapter is organized in two formats. The first section lists best practices for each energy technology, allowing users to quickly review issues particular to a proposed energy project. The second section includes some general guidance for siting structures to avoid physical obstructions, based on structure height and design observations by technology.

4.1 Best Practices Listed by Technology

Tables 4.1 through 4.5 show best practices listed by energy technology.

Table 4.1. Best practices for solar power.

SOLAR POWER			
Best Practice	**Who**	**When**	**Why**
Meet with FAA (and/or Block Grant State Aviation Departments), State DOTs, and Other Relevant State and Local Agencies/Entities	Airport, Energy Company	Planning	Avoid all impacts
Use Solar Glare Hazard Analysis Tool (SGHAT) Model	Airport, Energy Company	Planning	Avoid glare during siting of PV arrays
Use Notice Criteria Tool	Airport, Energy Company	Planning	Avoid physical penetration during siting
File Form 7460	Airport, Energy Company	Planning	Identify all impacts
Engage Stakeholder Process	Airport, Energy Company	Planning	Raise issues that can be addressed through agency review
Coordinate with Tower and Airport	Airport, Energy Company	Construction	Avoid airspace hazard
Issue Notice to Airmen (NOTAM)	FAA	Construction	Avoid airspace hazard; should only be used in short term (3-6 months) to call attention to potential safety hazard

Table 4.2. Best practices for wind power.

WIND POWER			
Best Practice	**Who**	**When**	**Why**
Use DoD Siting Tool	Energy Company	Planning	Avoid areas of significant radar activity
Use Notice Criteria Tool	Airport, Energy Company	Planning	Avoid physical penetration during siting
Meet with FAA (and/or Block Grant State Aviation Departments), State DOTs, and Other Relevant State and Local Agencies/Entities	Energy Company	Planning	Identify specific airspace issues
Engage Stakeholder Process	Energy Company	Planning	Raise issues that can be addressed through agency review
File Form 7460	Energy Company	Planning	Avoid impacts to flight paths and radar
Upgrade Facilities	Energy Company	Development	Mitigate for identified radar impacts
Apply Lighting/Marking to Wind Turbine	Energy Company	Development	Mitigate for airspace penetration
Apply Lighting/Marking to MET	Energy Company	Planning	Avoid airspace hazard
Issue Notice to Airmen (NOTAM)	FAA	Construction	Avoid airspace hazard; should only be used in short term (3-6 months) to call attention to potential safety hazard

Table 4.3. Best practices for oil and gas drilling.

OIL AND GAS DRILLING			
Best Practice	**Who**	**When**	**Why**
Meet with FAA (and/or Block Grant State Aviation Departments), State DOTs, and Other Relevant State and Local Agencies/Entities	Airport, Energy Company	Planning	Identify specific airspace issues
Use Notice Criteria Tool	Airport, Energy Company	Planning	Avoid physical penetration during siting
File Construction Safety Phasing Plan	Energy Company	Planning	Avoid airspace hazard
File Form 7460	Airport, Energy Company	Planning	Avoid airspace hazard
Plan Frack Ponds as Temporary Structures or Incorporate Wildlife Prevention Measures	Energy Company	Planning	Avoid wildlife hazards
Prohibit Flaring	Airport	Planning	Avoid airspace hazard
Coordinate with Tower and Airport	Airport, Energy Company	Construction	Avoid airspace hazard
Issue Notice to Airmen (NOTAM)	FAA	Construction	Avoid airspace hazard; should only be used in short term (3-6 months) to call attention to potential safety hazard

4.2 Siting Guidance and Design Criteria for Energy Structures

One of the directives of this research was to identify siting and design guidance for energy technologies, such as "height and distance criteria for wind turbines, distance and angular criteria for solar panels, and thermal plumes effects on aviation operations." After reviewing all of the available information, it was difficult to identify specific criteria. However, general siting guidance is possible based on FAA definitions of airspace and physical penetration. Design observations are also provided, organized by technology type.

Table 4.4. Best practices for power plant stacks and cooling towers.

POWER PLANT STACKS AND COOLING TOWERS			
Best Practice	**Who**	**When**	**Why**
Meet with FAA (and/or Block Grant State Aviation Departments), State DOTs, and Other Relevant State and Local Agencies/Entities	Energy Company	Planning	Identify specific airspace issues
Engage Stakeholder Process	Energy Company, Airport	Planning	Raise issues that can be addressed through agency review
Use Notice Criteria Tool	Energy Company	Planning	Avoid physical penetration during siting
File Form 7460	Energy Company	Planning	Avoid impacts to airspace
Use MITRE Model[1]	Energy Company	Planning	Predict characteristics of thermal plume
Use Air To Air Heat Exchangers or Other Plume Abatement Technology	Energy Company	Planning	Avoid impacts to airspace
Issue Notice to Airmen (NOTAM)	FAA	Construction	Avoid airspace hazard; should only be used in short term (3-6 months) to call attention to potential safety hazard

Notes:
1. The MITRE Plume Hazard Model has not been released by FAA as of this writing. Therefore, until release of the model and updated AC, air traffic controllers, pilots, and developers should rely on current FAA guidance and recommended practices, including the use of the CASA guidance where applicable.

Table 4.5. Best practices for electricity transmission infrastructure.

ELECTRICITY TRANSMISSION INFRASTRUCTURE			
Best Practice	**Who**	**When**	**Why**
Meet with FAA (and/or Block Grant State Aviation Departments), State DOTs, and Other Relevant State and Local Agencies/Entities	Energy Company	Planning	Identify specific airspace issues
Engage Stakeholder Process	Energy Company, Airport	Planning	Raise issues that can be addressed through agency review
Use Notice Criteria Tool	Airport, Energy Company	Planning	Avoid physical penetration during siting
File Form 7460	Energy Company	Planning	Avoid impacts to airspace
Apply Lighting/Marking, Spherical Balls	Energy Company	Planning	Avoid airspace hazard
Issue Notice to Airmen (NOTAM)	FAA	Construction	Avoid airspace hazard; should only be used in short term (3-6 months) to call attention to potential safety hazard

4.2.1 Siting Guidance

The general siting guidance shown in Table 4.6 has been developed for energy structures based on the typical height of structures currently being proposed by energy companies and airspace criteria included in Federal Aviation Regulations (FAR). The locations relative to an airport are shown graphically in Figure 4.1. Because these structures penetrate airspace, compliance with FAR Part 77 will ultimately be assessed by the FAA after conducting an aeronautical study through the filing of Form 7460. However, these general guidelines, if followed, will help avoid many conflicts.

4.2.2 Design Observations

Table 4.7 presents a summary of design observations for each of the technologies reviewed.

Table 4.6. Siting guidance.

SITING GUIDANCE				
Structure	**Height (ft. AGL)**	**Representative Structure**	**Distance Guideline (NM)[1]**	**Basis[2]**
Solar Tower	540	Crescent Dunes (Tonopah) Concentrating Solar Power Project[3]	6.4	FAR 77.23
Solar Panel	10	Typical	0.02	FAR 77.25
Meteorological Tower – Tall	330	Typical for 100 meter hub height	4.3	FAR 77.23
Meteorological Tower – Small	199	Typical	3	FAR 77.25
Wind Turbine – Tall	600	GE 2.5MW 120 meter hub height	7	FAR 77.23
Wind Turbine – Medium[4]	265	GE 1 MW Wind Turbine	3.6	FAR 77.23
Wind Turbine – Small[5]	155	Northern Power Systems 100 kW Wind Turbine	1.8	FAR 77.25
Drill Rig 1 – NoMAC	173	DFW	1.9	FAR 77.25
Drill Rig 2 – Mountain Rig	103	DFW	1.6	FAR 77.25
Oil / Water Tank	21	DFW	0.2	FAR 77.25
Communication Tower	70	DFW	0.6	FAR 77.25
Power Plant Stack	630	Turk Coal Plant, AR[6]	7.3	FAR 77.23
Cooling Tower	370	Fort Martin Power Plant, WV	4.7	FAR 77.23
Transmission Tower	150	Northern Pass Transmission Project	1.8	FAR 77.25
Drill Rig 2 – Mountain Rig	103	DFW	1.6	FAR 77.25

Notes:
1. Base point for distance measurement is assumed to be closest runway threshold at the airport.
2. FAR Part 77, "Objections Affecting Navigable Airspace."
3. Under construction; expected to be commissioned in late 2013.
4. Wind turbine sizes from DOE NREL: http://www.nrel.gov/wind/midsize_wind.html.
5. http://www.nrel.gov/wind/smallwind/.
6. Commissioned in December 2012.

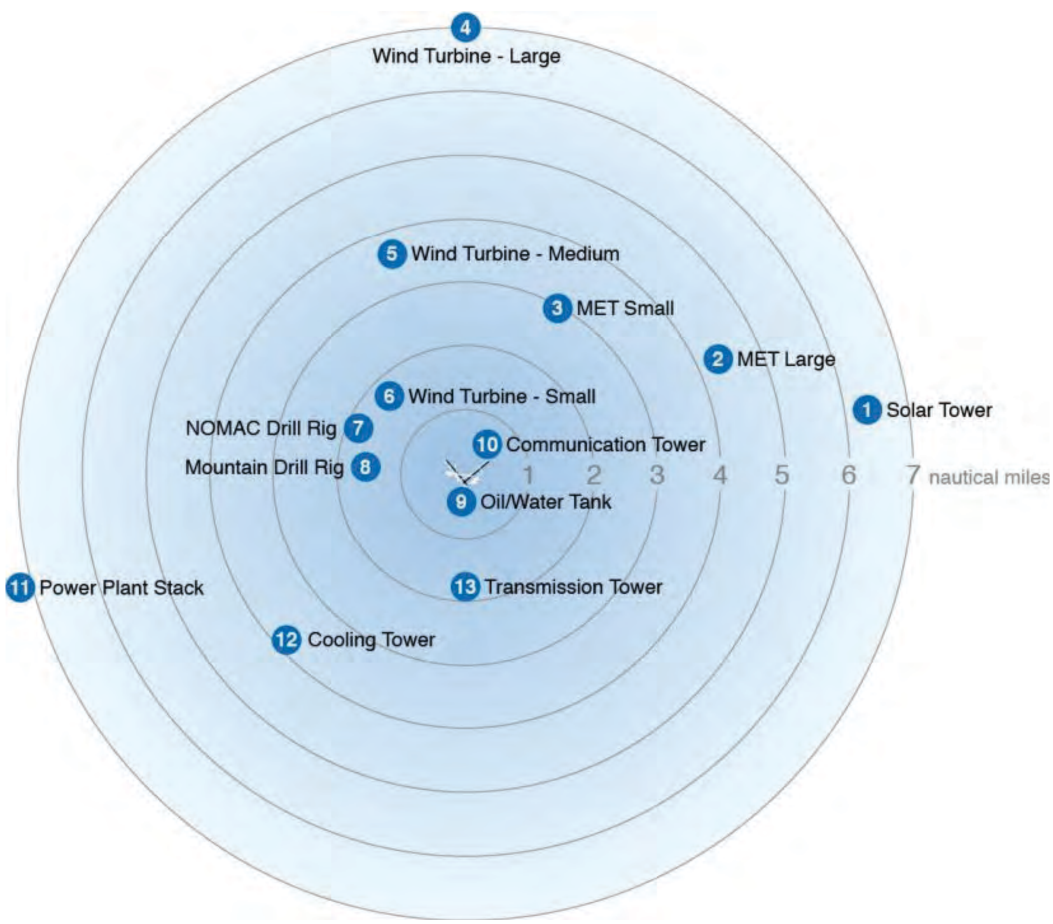

Figure 4.1. General guidance for siting distance for typical energy structures.

Table 4.7. Design observations.

Technology	Impact	Design Observation	Implementation
Solar PV	Glare	• PV module tilt and compass orientation have a significant impact on the direction of glare	Use SGHAT to evaluate impact
Wind Turbine	Radar	• There is no design flexibility with wind turbines because they must be tall to produce sufficient energy	Engage DoD Siting Clearinghouse and FAA
	Physical Hazard of METs	• All should be marked and located on aeronautical charts	File Form 7460
Oil and Gas	Flaring	• Prohibit flaring near airports as alternatives are available	Include in land lease and CSPP
	Wildlife Attractants	• Reclaim frack ponds after construction or include wildlife-deterrent designs	Include in land lease and CSPP
Power Plants	Thermal Plume Turbulence	• Sites should avoid areas of aircraft take-off and final approach below 1,000 ft. AGL	Utilize MITRE model[1]
Transmission	Physical Hazard	• All should be marked and located on aeronautical charts	File Form 7460

Notes:
1. The MITRE Plume Hazard Model has not been released by FAA as of this writing. Therefore, until release of the model and updated AC, air traffic controllers, pilots, and developers should rely on current FAA guidance and recommended practices, including the use of the CASA guidance where applicable.

CHAPTER 5

Moving Forward

The knowledge base related to potential safety impacts of energy technologies on airports and airspace has advanced considerably in recent years due to the efforts of the FAA and the ACRP. This work has been central to the identification of the best practices guidance captured in Chapter 4. When applied to individual projects, these best practices will help to mitigate, minimize, and even prevent harmful aviation safety impacts. Yet, important work in this research area is still necessary.

This section provides some summary conclusions of the research and new areas for potential research topics based on progress to date. In addition, this body of work supports recommendations for different parties involved in the airport and energy fields to increase opportunities to develop new energy projects on or near airports that may provide airport and local economic and environmental benefits while preserving airspace as a finite resource.

5.1 Conclusions on Current Status of Energy and Aviation

Based on the research conducted for this Guidebook, the following conclusions are evident:

1. Impacts of energy facilities are specific to the technology, so it is important to refer to the technology section when using this guidance.
2. Specific guidance and criteria that apply to all projects in a particular technology area are difficult to identify. However, applying evaluation tools is the best way to proceed in assessing impacts of individual projects.
3. With the exception of structures that rise to 200 ft. or greater above-ground level, there is broad uncertainty as to whether or not an energy development project will impact airspace because:
   a. Physical impacts of structures below 200 ft. depend on proximity to an airport and level and type of aviation activity specific to a given area and
   b. Non-physical impacts are not well defined.
4. Because many projects do not trigger a specific airspace review threshold, airports must monitor proposed development activity and notify the FAA about any projects of concern.
5. Solar PV projects at airports have a well defined process for evaluation and approval using SGHAT, which should effectively avoid impacts and streamline approvals.
6. There is no simple solution to wind energy and radar impacts, though the Sandia National Laboratories' current research effort appears to be a reasonable technological approach to mitigating some impacts and allowing both wind farm construction and airspace protection.
7. Marking of METs and notifying pilots is critical as evidenced by recent policy recommendations of the NTSB.
8. The FAA is developing guidance for future oil and gas drilling projects based on the experiences of airports like DFW, DIA, and IDI, which will be very helpful in facilitating projects that enhance airport revenue while protecting airspace.
9. Thermal plume impacts continue to be an area of concern for local stakeholders. Power plant developers should use the MITRE Model (when publicly available from FAA) and other models or guidance (i.e., CASA) to present information to federal permitting agencies to demonstrate that individual projects will not produce a hazard to fixed-wing aircraft.
10. The FAA and airports should develop a list of electricity infrastructure that does not comply with FAR Part 77 and work with electric utilities to include mitigation of those impacts as part of their infrastructure investment program.
11. Any project regardless of technology type should seek guidance from the FAA, state, and local airports early in the planning process to avoid impacts.

5.2 Future Work

5.2.1 No-Glare Solar Panel

The current solution to glare is to perform a glare analysis using SGHAT, which will help identify sites and designs that could be problematic. Another potential solution would be to deploy a solar panel that does not produce a reflection intensity that produces an ocular hazard. Research conducted as part of this project studied a number of commercially available solar modules and measured the amount of light reflected in a laboratory setting. One of the panels produced no specular reflection at the standard measurement incidence angle (20°) and less than 5 percent reflection at an incidence angle of 80 percent.

The Sandia National Laboratories are continuing to evaluate different PV samples to better understand the correlation between surface texturing (i.e., roughness) and light scattering, which has impacts on glare. Profilometry tests are being performed to quantify the roughness (i.e., mean height and frequency) on different samples. These parameters are being correlated to the amount of solar glare and scatter observed. The objective is to prescribe future guidelines for glass texturing and/or roughness parameters that will significantly reduce the potential for ocular impacts from solar glare on PV modules.

As part of this work, there is interest in deploying some of the deep-textured panels with a low level of reflection for investigation in the field. An inquiry has been made with the PV panel manufacturer to see if the panel can be obtained for this research. A potential challenge with deeply textured glass modules is its potential affinity to soiling. Additional studies are necessary to quantify the trade-off between soiling, glare, and transmission to the PV cell.

5.2.2 Wind Radar and Turbulence Research

Given the growth in wind power and its success in generating clean, cost-effective electricity, the expectation is that more wind farms will be constructed and aviation radar potentially compromised. The possible solutions to this problem are (1) prohibiting the construction of the wind farm, (2) moving the radar, or (3) applying some mitigation technology.

Mitigation technology may be the best option for achieving the two national objectives of constructing wind power and preserving national airspace. The fieldwork for the IFT&E Program was completed in Spring 2013 and results will be released in a series of reports available through the DOE Energy Efficiency and Renewable Energy (EERE) Wind Program web site.[123] There is likely to be additional work to advance mitigation technologies and Sandia National Laboratories will continue to lead that work. Aviation interests will need to continue their engagement in this research. Finally, the new Scaled Wind Farm Technology Facility, managed by the Sandia National Laboratories and Texas Tech University in Lubbock, TX, will add valuable research on turbine-turbine interaction, complex wind farm aerodynamics, and the effects of WTG turbulence on aircraft (see Section 3.2.3.2).

[123] DOE, EERE Wind Program: http://www1.eere.energy.gov/wind/rd.html.

5.2.3 Gain Experience with Modeling Tools

The research highlights availability of new modeling tools to help predict potential impacts from proposed projects. The modeling tools discussed include the following:

- SGHAT for glare (https://share.sandia.gov/phlux)
- Fraunhofer for wind turbine turbulence
- MITRE Thermal Plume Hazard Model for thermal plumes (when released by FAA)

The aviation industry should work with the organizations that developed these tools to identify cases where they were applied and what the impacts were. This research would provide information to help determine how often the tools are being used, how the results were evaluated against thresholds of impact, and if there are any changes that might be recommended based on lessons learned.

5.2.4 Status of Electric Transmission Infrastructure as an Obstruction

Some of the preliminary research on electric transmission infrastructure uncovered several instances where existing transmission lines are an airspace obstruction. The extent of the problem has not yet been evaluated and may require additional research on known obstructions and other electrical infrastructure that poses a potential physical hazard to aviation.

5.3 Coordination and Collaboration

Given that energy and transportation are two critical aspects of the public infrastructure with individualized missions and needs, it is important to create structured coordination and collaboration to ensure that each area can progress without impeding the other. The research has revealed a few specific areas for enhancement of coordinated collaboration in energy and aviation.

5.3.1 Interagency Coordination on Wind Energy Siting

On the federal government level, the FAA, DoD, and DHS each have a stake in protecting the NAS for provision of airspace resources to aviation users and protection of those

Table 5.1. Options for outreach to the energy industry.

Activity	Who	Why
Monitor local development activity	Airport, Aviation Stakeholders	Because project proponents that may not notify the airport are likely to be involved in a broader public discourse
Meet with local government officials	Airport, Aviation Stakeholders	Inform them about airport's interests in protecting airspace; local officials can also inform project proponents about need to communicate with airport
Collaborate on communications with State DOT	Airport, Aviation Stakeholders	State DOT can expand visibility of airspace protection communication efforts
Meet with the local utility company	Airport, Aviation Stakeholders	An annual meeting to discuss future projects might be successful in planning for airspace compatibility
Coordinate with national aviation interest groups	Airport, Aviation Stakeholders	Groups like the Aircraft Owners and Pilots Association track issues of concern to constituents and are active in airspace protection projects
Engage national energy associations	FAA, Airport Associations	Contact national associations for wind, solar, oil and gas, and energy generators about working groups, conferences, and other opportunities to inform their constituents about airspace impacts
Engage federal energy agencies	FAA, DoD, DHS	Contact federal agencies involved with encouraging energy research and communication to discuss airspace protection

resources for national security purposes. In addition, NOAA is keenly interested in protecting weather radars that could be adversely affected by wind farms. While these organizations have collaborated through such programs as the FAA Obstruction Evaluation/Airport Airspace Analysis (OE/AAA) review process and the DoD Siting Clearinghouse, it would be very effective if each could agree on consistent siting guidance for wind turbines. At present, the FAA has specific siting criteria that it uses in evaluating individual projects. The DoD relies on the siting clearinghouse process, which is in part cooperative with the FAA. The DHS has stated that it will be preparing siting guidance but nothing has been released at present. A coordinated siting approach could avoid confusion on the review of future projects and allow those that are compliant to be approved more swiftly. Furthermore, state government agencies, particularly in FAA Block Grant States, and local entities must also be involved in project planning and coordination efforts, as significant decisions are often most effectively achieved at the state and local level.

5.3.2 IFT&E Results

The IFT&E is a model interagency program that will provide important information about mitigating the impacts of wind farms on radar. The individual test results and associated recommendations are expected to achieve the following objectives (see Section 3.2.3.1):

- Accelerate the adoption of mitigation technologies by the radar community.
- Allow the sponsor agencies to make near-term and future investment decisions.
- Provide government agencies quantitative WTG interference data that can be used by government researchers to develop new mitigation technologies.
- Provide additional insights and a deeper scientific understanding into the phenomenology of wind turbine interference on radar systems for all stakeholders.
- Encourage participants to use their proprietary information garnered during the tests for product improvements.

The publication of the results should be an opportunity for the cooperating agencies to proceed on several fronts to implement the recommendations.

5.3.3 Outreach to Energy Industry

One of the important findings of this research is that only certain projects trigger an obvious airspace study and that many other projects may not be reviewed until a problem is identified during or after construction. Types of projects that may not be reviewed include solar PV off airport property, wind turbines and METs less than 200 ft. in height, oil and gas off airport property, and electricity transmission infrastructure. Projects that have resulted in airspace hazards after construction include METs and electric transmission towers. To minimize these occurrences, the aviation community needs to increase outreach to the energy industry, both formally and informally. Some of the options that the aviation community should consider are listed in Table 5.1.

APPENDIX A

List of Acronyms and Technical Terminology

Acronym	**Full Term**
14F	Hamlin Municipal Airport
A/R	Anti-reflective
AC	Advisory Circular
ACC	Air-Cooled Condenser
ACRP	Airport Cooperative Research Program
ADO	FAA Airport District Office
ADS-B	Automatic Dependent Surveillance — Broadcast
AFD	Airport/Facility Directory
AGL	(Distance) Above Ground Level
AIC	Aeronautical Information Circular
AIDS	FAA Accident/Incident Data System
AIM	FAA Aeronautical Information Manual
ALP	Airport Layout Plan
AMSL	(Distance) Above Mean Sea Level
ANC	Ted Stevens Anchorage International Airport
AOA	Air Operations Area
AOPA	Aircraft Owners and Pilots Association
APP	FAA Office of Airport Planning and Programming
ARAP	Adjunct Radar Analysis Processor
ARP	FAA Airports organization
ARTCC	Air Route Traffic Control Center
ASDE-X	Airport Surface Detection Equipment — Model X
ASR	Air Surveillance Radar
ASRS	FAA Aviation Safety Reporting System
AT OES	FAA Air Traffic Obstruction Evaluation Office
AT OSG	FAA Air Traffic Operation Service Group
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
ATO	FAA Air Traffic Organization
AWEA	American Wind Energy Association
BLM	U.S. Bureau of Land Management
BOEM	U.S. Bureau of Ocean Energy Management
Btu/BTU	British thermal unit
CAA	United Kingdom (UK) Civil Aviation Authority
CAP	UK CAA Civil Aviation Publication
CASA	Australia Civil Aviation Safety Authority

CEC	California Energy Commission
CFD	Computational Fluid Dynamics
CFR	U.S. Code of Federal Regulations
CO_2	Carbon Dioxide
COTS	Commercial Off-the-Shelf
CREZ	Competitive Renewable Energy Zone
CSP	Concentrating Solar Power
CSPP	Construction Safety Phasing Plan
Data Comm	Data Communications
dBsm	Decibel per Square Meter
DEN	Denver International Airport
DFW	Dallas/Fort Worth International Airport
DHS	U.S. Department of Homeland Security
DME	Distance Measuring Equipment
DNI	Direct Normal Irradiance
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOI	U.S. Department of Interior
DOT	U.S. Department of Transportation
EERE	Office of Energy Efficiency & Renewable Energy
EIA	U.S. Energy Information Agency
EMI	Electomagnetic Interference
EPA	U.S. Environmental Protection Agency
ERCOT	Electric Reliability Council of Texas
FAA	U.S. Federal Aviation Administration
FAR	U.S. Federal Acquisition Regulation
FERC	U.S. Federal Energy Regulatory Commission
FMS	Flight Management System
FMV	Fair Market Value
FOD	Foreign Objects Debris
FP	FAA Office of Flight Procedures
FS	FAA Office of Flight Standards
G	G-force (Unit of Physical Force Measurement)
GA	General Aviation
GPS	Global Positioning System
GUI	Graphical User Interface
GW	Gigawatt
HMMH	Harris Miller Miller & Hanson Inc.
HMR	Helicopter Main Route
HRSG	Heat Recovery Steam Generator
IDI	Jimmy Stewart Airport
IFC	International Finance Corporation
IFR	Instrument Flight Rules
IFT&E	Interagency Field Test and Evaluation Program
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IRAC	NTIA Interdepartment Radio Advisory Committee
JLUS	DoD Joint Land Use Study
JPDO	Joint Planning and Development Office
kV	Kilovolts
LIDAR	Light Direction and Ranging (Technology)
m/s	Meters per Second

MET	Meteorological Evaluation Tower
MHT	Manchester-Boston Regional Airport
MIT	Massachusetts Institute of Technology
MOA	Military Operations Area
MSL	(Distance Above) Mean Sea Level
MTI	Moving Target Indicator
MTD	Moving Target Detection
MW	Megawatt
NAAA	National Agricultural Aviation Association
NAS	National Airspace System
NASDAC	FAA National Aviation Safety Data Analysis Center
NAVAID	Navigational Aid
NEPA	National Environmental Policy Act
NextGen	Next Generation Air Transportation
NHTSA	National Highway Transportation Safety Administration
NM/nm	Nautical Miles
NOAA	U.S. National Oceanic and Atmospheric Administration
NOTAM	Notice to Airmen
NRDC	Natural Resources Defense Council
NTAP	Notice to Airmen Publication
NTIA	U.S. National Telecommunications and Information Administration
NTSB	U.S. National Transportation Safety Board
OAPM	FAA Optimization of Airspace & Procedures in the Metroplex
OEA	Office of Economic Adjustment
OE/AAA	FAA Obstruction Evaluation/Airport Airspace Analysis
OFA	Object Free Area
OPD	Optimized Profile Descent
P.L.	U.S. Public Law
PAT	Plot Amplitude Thresholds
PBN	Performance-Based Navigation
PD	Probability of Detection
PV	Photovoltaics
RADAR/radar	Radio Direction and Ranging (Technology)
RAG	Radio Azimuth Gate
RCS	Radar Cross Section
REPI	DoD Readiness and Environmental Protection Integration
RNAV	Area Navigation
RNP	Required Navigation Performance
RPS	Renewable Energy Portfolio Standards
RPZ	Runway Protection Zone
RVSM	Reduced Vertical Separation Minimum
SACTI	Seasonal Annual Cooling Tower Impact
SGHAT	Solar Glare Hazard Analysis Tool
SMS	Safety Management System
SNL	Sandia National Laboratories
SOC	Systems Operations Center
SRM	Safety Risk Management
SSR	Secondary Surveillance Radar
SWW	Hamlin and Avenger Field Airport
Tech Ops	FAA Office of Technical Operations
TERPS	U.S. Standard for Terminal Instrument Procedures
TLS	Target Level of Safety

TRACON	Terminal Radar Approach Control
TRANSCOM	U.S. Transportation Command
TRB	Transportation Research Board
UAS	Unmanned Aircraft Systems
USAF	U.S. Air Force
USDA	U.S. Department of Agriculture
VFR	Visual Flight Rules
Vision 100	Vision 100 — Century of Aviation Reauthorization Act (P.L. 108-176)
VMC	Visual Meteorological Conditions
VOR	VHF Omnidirectional Range
VORTAC	VHF Omnidirectional Range/Tactical Aircraft Control
WTG	Wind Turbine Generator

APPENDIX B

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APPENDIX C

Accident Report Data

To understand the safety concerns in the NAS that could be caused by energy facilities and production, historical accident data were reviewed and analyzed. In this task, analysis of historical accident data is based on compiling aviation accident reports and databases. Energy facilities considered in this research include solar power facilities, wind turbines and traditional power plants. According to the initial database review, there are very few accident/incident records directly related to energy facilities. Thus, we adjusted the approach and searched for accidents due to potential safety impacts that could be caused by energy facilities and production listed in *ACRP Synthesis 28.*

C.1 Data Source

There are three major aviation safety databases: Aviation Safety Reporting System (ASRS)[1], Aviation Safety Network (ASN)[2] and Aviation Accident Database (AAD)[3]. In addition, the FAA is constructing the aviation safety information analysis and sharing system (ASIAS). ASRS is a repository of voluntary reports and collects confidential safety information from frontline personnel in aviation. ASN is supported by the Flight Safety Foundation, and AAD is supported by the National Transportation Safety Board (NTSB). The characteristics of the three databases are quite different (see Table C-1). Figure C-1 shows the number of records in the three safety databases from 2007 to 2012.

In this Guidebook, the researchers chose ASRS as the safety database for further investigation. A pilot search experiment shows that there are very few accidents directly related to energy systems but there are many accidents caused by safety impacts (e.g., glare or turbulence) which could be caused by energy facilities.

C.2 Text Mining of Safety Data

The safety data are semi-structured data, which include structured parts and unstructured parts. The structured parts usually show place, time, and types of flight and so on. Unstructured data are free text. Structured data can be expressed as a relational table with fields and can be easily summarized and classified. Classification and query of the structured part are well developed in present aviation safety databases. The analysis process of unstructured data highly depends on researchers' experiences and knowledge. Text mining tools are being developed to improve the efficiency of human analysis on unstructured data. Functions of these tools include Clustering, Document Retrieval, and Classification. In this research project, a new document retrieval method was developed to help retrieve accurate information from unstructured data in the large size air traffic safety database. The first step of the new method was sample analysis, including establishment of keywords dictionary, and calculation of weights of keywords, Critical Point and Max Distance. The Critical Point expresses average keywords frequency of samples. Max Distance is the maximum distance from samples to the Critical Point. The second step was to search similar records with samples, which were based on the Distance Rule. Distance Rule is arithmetic to calculate the distance to Critical Point, considering not only the frequency of keywords but also the weights of keywords.

C.3 Case Study

The new method was applied to search for incidents caused by the effects of glare. Figure C-2 presents the number of glare incidences reported in the ASRS annually from 2007 to 2012. The total number of reports over the 6 year period is

[1]Aviation Safety Reporting System Database, http://asrs.arc.nasa.gov/search/database.html. Accessed on October 10, 2012.
[2]Aviation Safety Network, http://aviation-safety.net/index.php. Accessed on December 8, 2012.
[3]Aviation Accident Database, http://www.ntsb.gov/aviationquery/index.aspx. Accessed on October 10, 2012.

Table C-1. Comparison of air traffic safety databases.

	ASRS	ASN	AAD
Size of data	Large	Small	Medium
Covered Regions	Worldwide	Worldwide	US
Search Functions	Excellent	Limited	Good
Export Format	CVS, Word, Excel	None	XML, Text

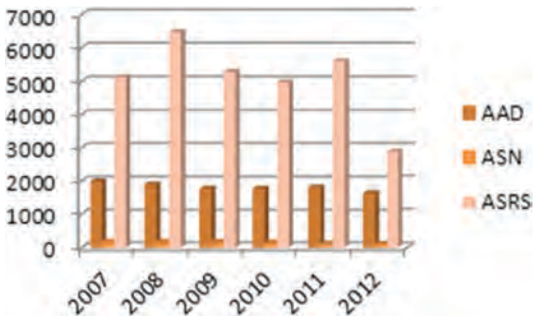


Figure C-1. Comparison of data size (2007–2012).

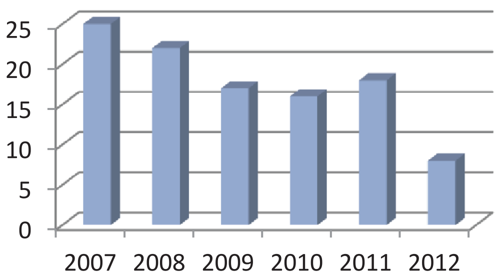


Figure C-2. Glare incidences by year.

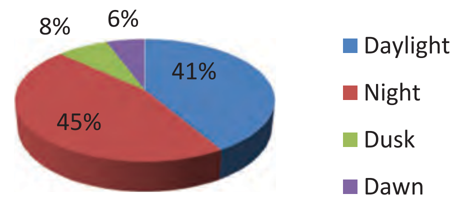


Figure C-3. Glare incidences by time of day.

106. Note that the glare came not only from energy facilities (e.g., concentrated solar power [CSP]), but also from a variety of sources, such as the reflection of lights from the glass walls of buildings. Further investigations were conducted to understand the time and flight phases when the glare incidents occurred. Figure C-3 shows that most glare incidents happened either in the day or at night but very few of them occurred during dusk or dawn. In addition, Figure C-4 compares the incidents occurring in different flight phases in the day or at night. It shows that during the day, incidents are evenly distributed in different flight phases, but at night, the incidents are more likely to occur during approach and taxi phases. This observation provides further insights for aviation safety management.

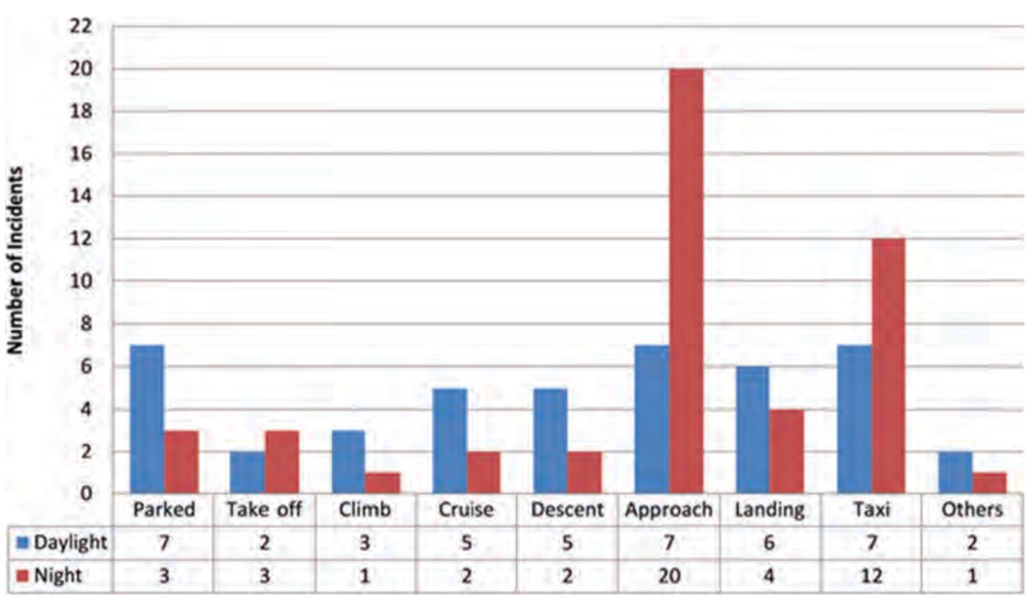


Figure C-4. Statistics of glare incidents by flight phases in the day and at night.

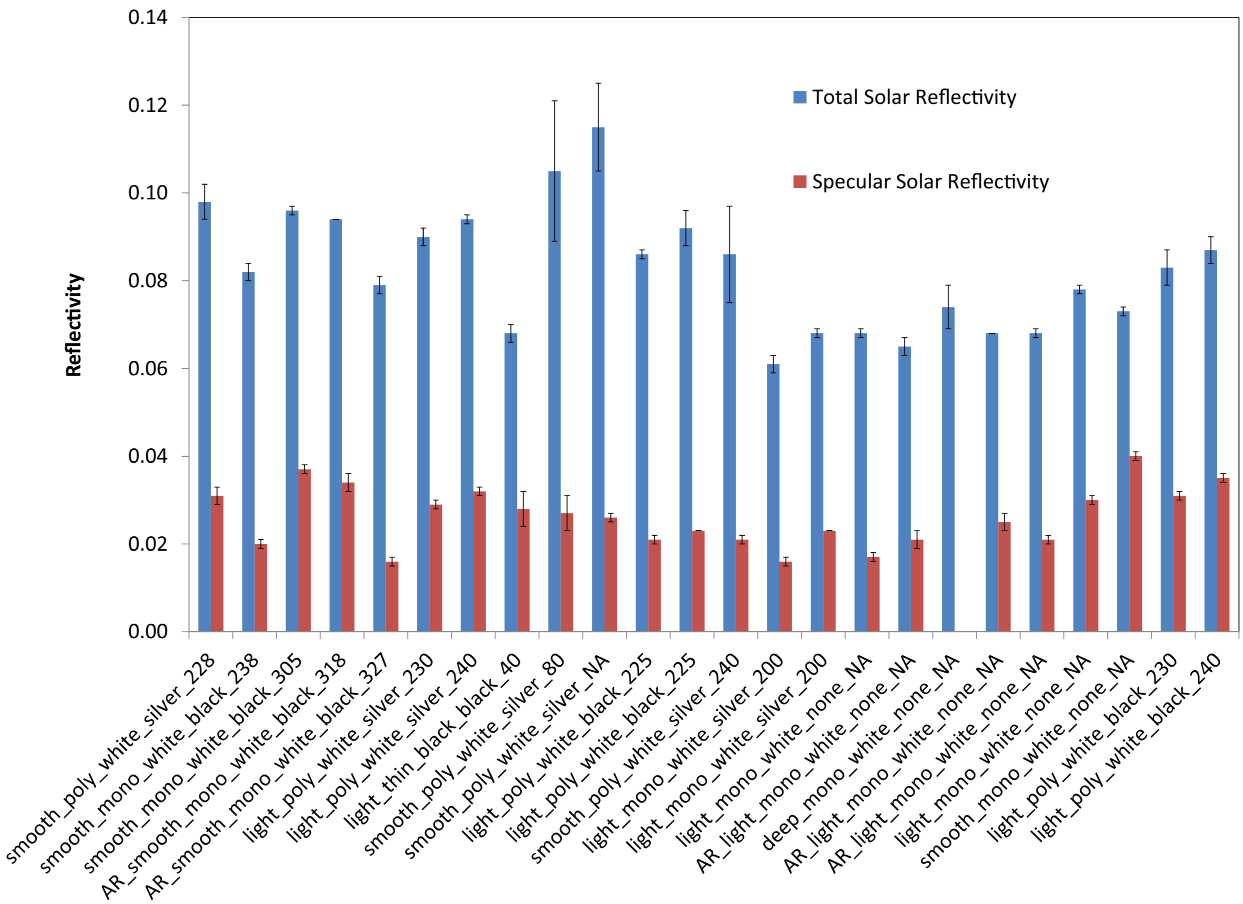
APPENDIX D

Solar Module Reflectivity Testing Data

In research for preparation of this Guidebook, testing was performed to measure solar reflectivity of different PV modules to determine the potential impact of glare. PV modules and samples from different manufacturers were obtained, and the solar reflectance (total and specular) was measured on 24 different samples using a Surface Optics Corporation 410 Solar Reflectometer (see Figure D-1). The incidence angle of the light source in the 410 Solar was 20 degrees. Results show relatively similar reflectance values and behavior for all the samples.[1] The total solar reflectivity generally ranged from 6 to 12 percent, while the specular solar reflectivity ranged from approximately 1 to 4 percent. Interestingly, the deep-textured glass sample did not show any measurable specular reflectance, which indicates a significant amount of scattering of the reflected light relative to smooth or lightly textured surfaces. Smooth surfaces, such as mirrors and smooth glass, produce more specular reflections with greater intensity and tighter beams (i.e., larger retinal irradiances and smaller subtended angles), while solar receivers, textured glass, and anti-reflective coatings produce more diffuse reflections with lower solar intensities but greater subtended angles (see Figure D-2). However, it is important to note that these values are for an incidence angle of 20 degrees. At higher incidence angles, the reflectivity can increase significantly.

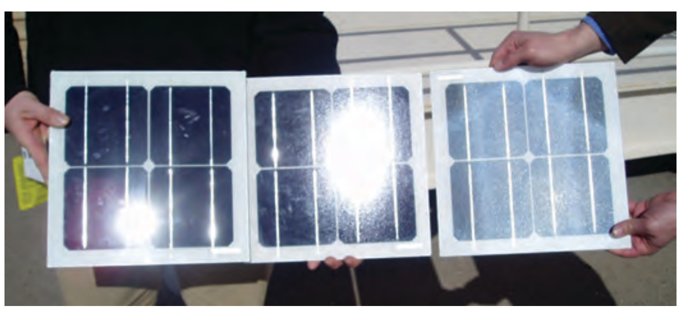
Also as part of the testing, the reflectivity of selected PV samples as a function of incidence angle was measured using an illuminance meter and lasers (see Figure D-3). Reflectivity measurements at incidence angles of 20, 40, 60, 70, and 80 degrees for different types of PV modules were made (e.g., glass texture, anti-reflective coating, etc.). Figure D-4 shows that nearly all of the results follow a consistent trend—the near-normal reflectivity is approximately 1 to 4 percent, remains stable (and even decreases slightly) until 60 degrees, and then increases significantly beyond 60 degrees. Only the deep-textured glass sample yielded reflectances that remained below 5 percent above an incidence angle of 70 degrees. For several samples, we also measured the reflectivity when aiming the laser over different parts of the module—the cell, the metal tabs, the backsheet, and the frame. We found that the area-weighted average of the reflectance was not significantly affected by the non-cell areas, so only the reflectivities measured over the cells were reported in Figure D-4.

[1] The area-weighted solar reflectance was not significantly affected by reflectance values measured over the non-cell areas (i.e., backsheet, frame, metal tabs).



Note: Total and specular values, recorded using 410 Solar reflectometer with 20° incidence angle and 6° specular acceptance angle.

Figure D-1. Measured solar reflectance values from different PV modules and samples.

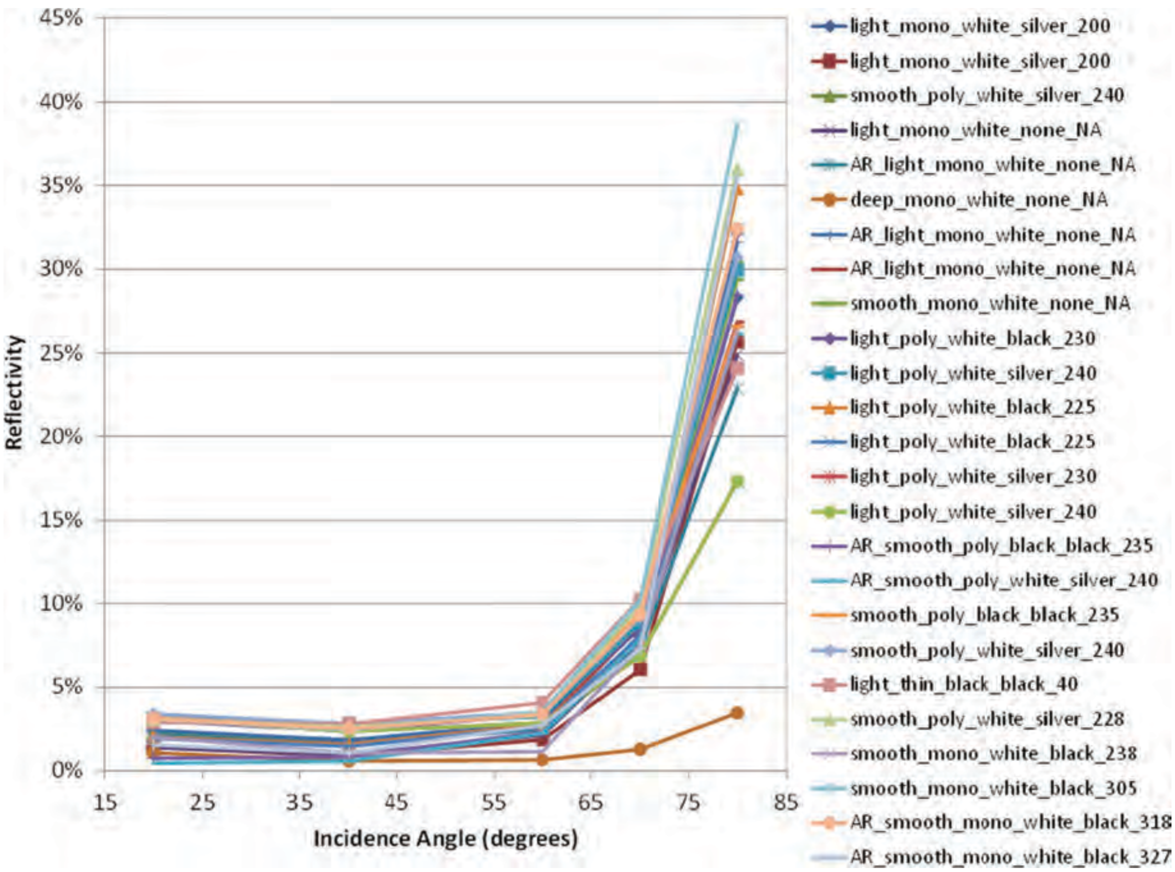


Left: Smooth float glass; Middle: Glass with anti-reflective coating;
Right: Deeply textured glass.
Source: Canadian Solar, Inc.

Figure D-2. PV glass samples resulting in different solar glare intensity and size.

Note: Measured as a function of incidence angle, using laser pointers and an irradiance meter.

Figure D-3. Measuring reflectivity.



Notes:

1. Measured as a function of incidence angle.
2. Nomenclature for labeling: "AR_glass-texturing_cell-type_backsheet-color_frame-color_power-rating"
   a. AR: Anti-reflective coating was present
   b. Glass-texturing: smooth (none), light, or deep
   c. Cell-type: monocyrstalline or polycrystalline
   d. Backsheet-color: white or black
   e. Frame-color: silver or black
   f. Power-rating: power rating (in Watts)

Figure D-4. Reflectance of different PV modules.

APPENDIX E

Pilot Glare Survey Data

A flight crew survey was designed and supported in collaboration with the National Academy of Sciences (NAS) to obtain empirical information from pilots on the sources of solar glare and their effects. The methodology, design, analysis of results, and recommendations are discussed below.

Methodology

The survey was hosted online and web links were sent to various commercial passenger airlines and general aviation terminals across the country over a period of 9 months between October 2012 and July 2013. The survey was distributed through a variety of sources including airports, airlines, pilot associations, and other aviation professionals. The support of the Aircraft Owners and Pilots Association (AOPA) and the Air Line Pilots Association in distributing the survey through their e-newsletters was particularly important to increasing the number of responses.

Airports with known solar facilities prior to survey responses are listed in Table E-1 below. Most of the selected airports experience a significant annual volume of general aviation (light and business) aircraft carrying private passengers and serving recreational and training flight operations. These general aviation aircraft normally utilize a private passenger terminal operated by any number of companies providing needed services and facilities. The companies providing such services are commonly referred to as fixed base operators (FBOs). The survey was well supported by FBO managers who posted survey notice flyers in flight crew lounges and planning areas.

The responses were evaluated quantitatively and validated against textual comments provided by respondents.

Design

The 21 question anonymous survey was designed to systematically evaluate the following:

- General Experiences with Solar Glare
- Airport Solar Energy Facility Awareness
- Photovoltaic Solar Panel Awareness and Glare Experience
- Safety Concerns and Reporting Actions

Results and Analysis

General Experience of Solar Glare (Not Necessarily from Solar Panels)

There were 383 total survey responses, 32% of which came from pilots based at airports with known solar energy facilities listed in Table E-1. Commercial airline pilots were the largest group of respondents (54%) followed by single engine aircraft pilots (26%) as depicted in Figure E-1.

Frequency and Sources: Most respondents noticed some form of solar glare occasionally, concentrated during the time periods around sunrise or sunset.

In addition to the low angle of the sun at these times, other sources of reflective glare by order of magnitude include water bodies such as lakes and ponds, glass buildings, windows, and building roofs.

Phase of Flight: Arrival phase of flight had the highest quantitative score for glare observations. However, several respondents provided additional comments that they experienced solar glare during both arrival and departure (low altitude) phases of flight. These glare observations were assessed as a moderate nuisance and mitigated most often by cockpit shading and sunglasses.

Airport Solar Energy Facility Awareness: Only 43% of respondents were aware of existing solar energy facilities at or near the airports where they operate aircraft. Of this sub-group, 66% of respondents identified the facilities as photovoltaic with the remainder being concentrating solar power.

Solar Photovoltaic (PV) Panel Awareness: Among the group of respondents aware of these solar energy installations,

Table E-1. U.S. airports with solar photovoltaic energy facilities.

Airport	Identifier	State	Airport	Identifier	State
Bagdad	E51	AZ	Kahului	OGG	HI
Prescott	PRC	AZ	Kona International	KOA	HI
Phoenix	PHX	AZ	Lihue	LIH	HI
Bakersfield – Meadows Field	BFL	CA	Boston Logan International	BOS	MA
Burbank – Bob Hope	BUR	CA	Hanscom Field	BED	MA
Fresno Yosemite International	FAT	CA	Baltimore Washington International	BWI	MD
Long Beach International	LGB	CA	Charlotte/Douglas International	CLT	NC
Metropolitan Oakland International	OAK	CA	Person County	TDF	NC
Redding Municipal	RDD	CA	Manchester	MHT	NH
San Francisco International	SFO	CA	Albuquerque International	ABQ	NM
San Jose International	SJC	CA	Seneca County	16G	OH
Denver	DEN	CO	Chattanooga – Lovell Field	CHA	TN
Garfield County (Rifle)	KRIL	CO	Smyrna	MQY	TN
Gainesville Regional	GNV	FL	San Antonio International	SAT	TX
Lakeland Linder Regional	LAL	FL	St. Thomas	STT	VI
Tallahassee Regional	TLH	FL	Burlington International	BTV	VT
Hilo International	ITO	HI			

Source: HMMH

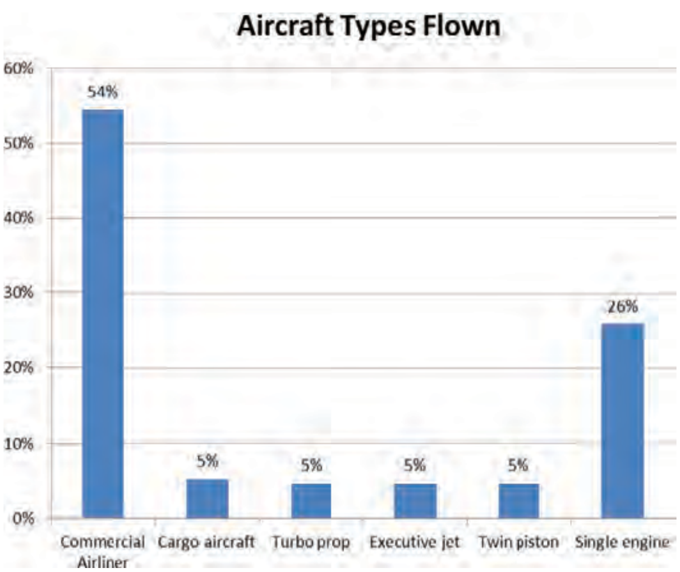


Figure E-1. Survey respondents by aircraft types flown.

26% affiliated solar glare experienced while flying with the facilities at or in the vicinity of the airports while 56% did not affirm that glare came from solar energy cells. The remaining 17% of respondents were uncertain.

Of the 26% who affiliated glare while flying with solar facilities, 31% listed facilities as concentrating solar power, while 25% listed facilities as solar PV. The remaining 44% were not certain what type of solar facility was present.

Solar PV Panel Glare: Generally, 45% of respondents were specifically aware of solar PV facilities at various airports. Among these respondents only 9% said they experienced glare specifically from solar PV facilities and mostly (88%) during the landing phase of flight. Of this notably small group, most (72%) did not find solar PV glare a nuisance or safety concern. Even fewer have expressed specific safety concerns to authorities regarding solar PV installations.

Abbreviations and acronyms used without definitions in TRB publications:

A4A	Airlines for America
AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
HMCRP	Hazardous Materials Cooperative Research Program
IEEE	Institute of Electrical and Electronics Engineers
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
MAP-21	Moving Ahead for Progress in the 21st Century Act (2012)
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
PHMSA	Pipeline and Hazardous Materials Safety Administration
RITA	Research and Innovative Technology Administration
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation